Magnetic field errors and non-axisymmetric behaviour of the plasma in RFX

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Introduction

RFX is a RFP experiment operating in Padua with R=2 m and a=0.457 m /1/. The device is equipped with a thick shell to stabilize MHD modes in the plasma. On the other hand, the shell equilibrium currents are forced to deviate at the two poloidal insulating gaps causing a local distortion of the magnetic field configuration. The experience of other RFP devices has clearly shown the importance of minimizing magnetic field errors at the gaps to improve discharge parameters and to increase its duration /2,3/. In RFX, sixteen coils, making up the so called Field Shaping Winding, have been located around the torus in order to generate part of the equilibrium field and produce a m.m.f equal and opposite to the plasma m.m.f. An accurate programming of the currents in this winding has been sought to get as close as possible to an axisymmetric magnetic configuration. A detailed analysis of the magnetic configuration is allowed by the RFX magnetic measurement system /4/. In particular, for the analysis presented in this paper, the measurements of the B_{ϑ} component of the magnetic field have been provided by 8 poloidal arrays of pickup coils and by 2 toroidal arrays of 72 pickup coils, lying at 22.5° from the equatorial plane of the machine, on its inner and outer side; moreover, poloidal flux loops, Rogowski coils, saddle coils mounted at the gaps have been used.

Field error effect on plasma discharge performance

Several pulses (from 1770 to 1880) have been dedicated to study the horizontal equilibrium and to minimize the field error at the poloidal gaps throughout the discharge by properly programming the 8 Field Shaping Winding (FSW) thyristor amplifiers. All the pulses were executed with the same initial applied loop voltage (360 V) and the same magnetic energy initially stored in the magnetizing winding (29 MJ). Moreover, the flat-top poloidal amplifiers were always active in the examined cases and a steady-state vertical field was applied to reduce the plasma outward shift /5/.

To characterize the quality of the magnetic configuration, for each pulse we evaluated the poloidal field error by taking the average of the absolute values of the measurements provided by the couples of saddle coils spanning the two poloidal gaps of the machine. This result has then been normalized with respect to the zero-order poloidal field at the plasma edge and time averaged during the flat-top in order to allow the comparison among different shots.

Typical results in terms of plasma current are shown in fig 1: pulse 1774 has been obtained controlling only the current of the outermost coil, while pulse 1860 is a significant example of an effective open loop programming of all the eight FSW amplifiers. The reduction of the time averaged relative field error from 15% to 6% resulted in an increase of duration of about 30 ms.

As an example of incorrect programming, pulse 1853 is presented, where the relatively short duration is due to an excess of external vertical field with respect to the ideal configuration. Fig. 2 shows the general trend of the pulse duration vs. average relative field error, for shots with $2.5 \cdot 10^{-14} < I/N < 5 \cdot 10^{-14}$ Am, $1.5 < \Theta < 1.6$ and steady state vertical field Bv=6 to 8 mT. The pulse duration is defined by the loss of field reversal.

As a matter of fact, duration is also affected by the switching off instant of the flat-top amplifier; this is the case for pulses longer than 85 ms.

Toroidal distortions of the poloidal field configuration

The toroidal arrays of pickup coils have been used to investigate the toroidal distortion of the configuration due to the penetration of the magnetic field through the gaps. In order to get rid of systematic uncertainties, the calibration constants have been corrected by imposing a condition of toroidal axisymmetry when the field error at the gaps, measured by the saddle coils, vanishes (usually at about 15 ms). In fig.3 the poloidal field measured by the outer array of probes is shown as a function of the toroidal angle at different times (shot 1860). The position of the gaps is characterized by two peaks of growing amplitude and constant width. The toroidal extension of the gap effect, defined as the region where the poloidal field distortion is not lower than 10% of its maximum value, has been estimated to be 40° (20° on each side) and does not vary significantly throughout the discharge. A periodicity of order 24 is also present, possibly due to the effect on the plasma of the toroidal field ripple, which is produced in RFX by 48 coils.

In order to compare the field penetrated through the gaps with the vertical field diffused across the shell, the non-axisymmetric component of the vertical field has been evaluated in the gap region on the basis of the measurements of the outer and inner poloidal pickup coils. A measure of the average vertical field across the whole shell is then obtained by taking the difference between the signals of the outermost and the innermost poloidal flux loop. The results for the two fields, starting from the axisymmetry condition instant, are shown in fig.4 (shot 1860). The field through the gaps accounts for a substantial part of the total field; the difference, which is growing in time, can be associated with the decay of the shell equilibrium currents.

Evaluation of the local plasma shift near the gaps

The local horizontal plasma shift at the gap has been estimated on the basis of a first order approximation of the equilibrium magnetic configuration /6/. The m=1 B_ϑ cosine component has been calculated as the difference between the measurements of the inner and outer pickup coils closest to the gap, while the m=1 B_r sine component has been derived from the measurements of the saddle coils across the gaps. These signals are measured on the shell inner surface, where the fields present maximum amplitude, therefore this is the highest estimate of the horizontal shift.

In fig.5 the shifts for the same pulses shown in fig.1 are presented. As expected, in shot 1774 the plasma column is significantly shifted outwards due to the insufficient equilibrium field, while the inward shift of shot 1853 is consistent with an excess of external equilibrium field. In shot 1860, characterized by a better programming of the FSW amplifiers, the local shift turned out to be much smaller, even if larger than the average plasma column shift, about 1.2 cm for this discharge. The slight equilibrium field defect still occurring at the gaps accounts for this discrepancy.

The average radial field, measured by the saddle coils at the gaps, is shown for a typical shot in fig.6 (shot 1823). A remarkable feature of this graph is the different behaviour observed at the two gaps. This is confirmed by fig.7, where time averages of the absolute values of the relative radial fields at the two gaps are correlated. The data show that the radial field can be larger than 1% either at one gap or at the other. The radial field can be related to a local vertical shift of the plasma column, but the relationship depends on the plasma horizontal shift.

In the shots where either gap exhibits a high radial field, evidence of enhanced local interaction with the first wall at the same toroidal position is given by CCD camera recordings.

Conclusions

Analysis of RFX shots confirmed the importance of an accurate control of the field errors at the gaps to improve discharge performance. The presence of the poloidal gaps has proven to be a major cause of non axisymmetric behaviour of the plasma column. A reduction of the local horizontal shift at the gaps can be obtained with an effective programming of the FSW amplifiers.

References

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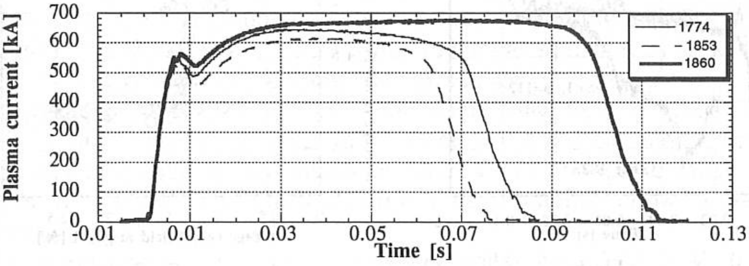

Fig.1

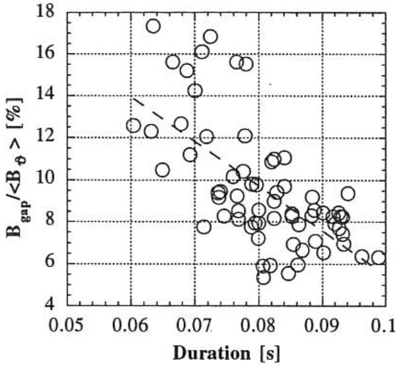

Fig.2

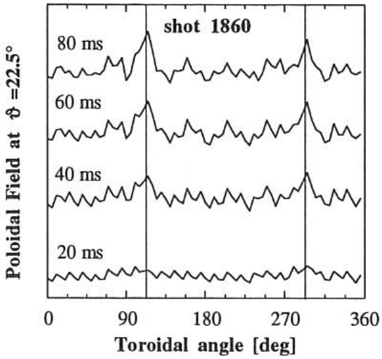

Fig.3

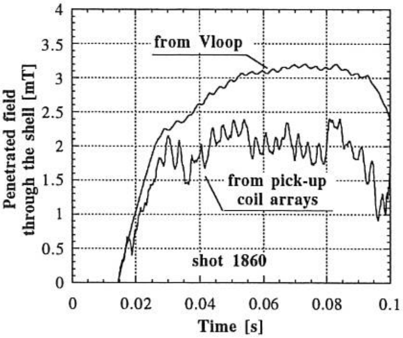

Fig.4

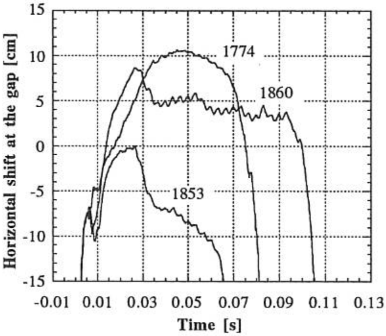

Fig.5

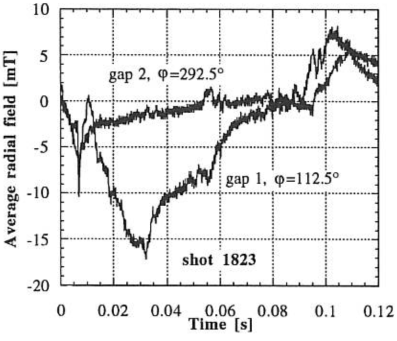

Fig.6

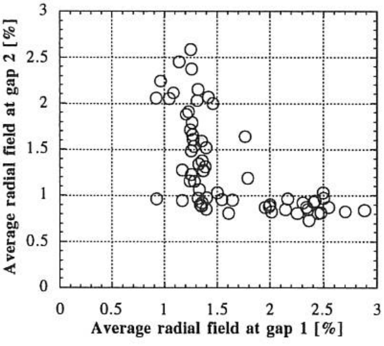

Fig.7