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INSIGHTS ON OHMIC INPUT POWER EVALUATION IN THE RFX-MOD REVERSED FIELD PINCH

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1. Introduction

Understanding the relationship between an applied electric field and the generated current density in Reversed Field Pinch (RFP) plasmas is a particularly interesting problem, due to the complexity of the physical phenomena involved. In fact, it is widely recognized by both theory and experiment that the simple local relation, valid in stationary conditions, between the loop voltage and the toroidal plasma density current:

$$V_{loop} = 2\pi R\eta(r)J_t(r)$$

using for $\eta(r)$ the Spitzer resistivity, cannot fully describe the RFP dynamics [1]. Instead it is more correct to compare the measured V_{loop} values with the voltage related to a global power or helicity balance. It is of course also of practical interest to understand if the experimentally required loop voltage corresponds to what expected or if additional 'anomalous' terms, that could be avoided, play a role. Similar arguments can be applied to the ohmic input power. As comparison with the experimental case, in this paper some RFX-mod [2] data will be shown, first for standard discharges and then, for discharges with transient modifications of plasma properties such as density (pellet injection) or magnetic energy (OPCD operations), where the evaluation of the ohmic input power time evolution is particularly delicate.

2. Experimental results and statistical analysis

Since global discharge characteristics are important in the correct evaluation of the ohmic power from experimental data, experiments with the most complete diagnostic coverage were selected from the RFX-mod database. In particular measured electron temperature and density profiles were used, as well as experimental estimates of the mean ion charge Z_{eff} from spectroscopic measurements of visible bremsstrahlung. Z_{eff} profile has been instead assumed from simulations. The main uncertainties left are about ion temperature that is not measured and was assumed equal to the electron one, and about internal magnetic profiles that are reconstructed using the α-Θ_0-β_0 model [3] starting from experimental F (defined as $B_\phi(a)/<B_\phi>$), Θ (defined as $B_\theta(a)/<B_\phi>$) and pressure profile measurements (note that as for the pressure, experimental profiles are used and no a-priori parameterisations were assumed). A sensitivity study was performed in order to assess the influence of the parameterisation chosen for the internal magnetic profiles; the result was that the uncertainties introduced are well inside the error bars of the experimental measurements. Globally the simple power balance case can be written as:

(1) $V_t I_t + V_p I_p = \frac{dU_m}{dt} + P_{Ohm\_\exp}$

from which an experimental ohmic power can be estimated as:

(2) $P_{Ohm\_\exp} = V_t I_t + V_p I_p - \frac{\mu_0}{2} R_0 a^2 \frac{d(L_{B^2} I_t^2)}{dt}$

assuming the knowledge of the time behaviour of the plasma inductance L_{B^2}.

This P_{Ohm_exp} can be compared with $P_{Ohm\_Spitzer}$ evaluated as:

$P_{Ohm\_Spitzer} = \int \eta_{Spitzer} j^2 dV$; where $\eta_{Spitzer} = 5.22\times10^{-5} \frac{Z_\sigma \cdot \ln\Lambda}{T(eV)^{3/2}} \Omega m$, and Z_σ is defined following [4] as a function of Z_{eff}. The blue diamonds in Fig. 1 clearly show that, as expected, the Spitzer simple formula cannot account for the whole measured P_{ohm} and that additional corrections are needed; the point spread in Fig1 is mainly due to the large error in the Z_{eff} measurement. Since neoclassical effects are present also in the RFP toroidal plasmas, we considered the presence of a fraction of trapped particles F_T that increases the plasma resistance by a factor $1/(1-F_T)$. The trapped particle fraction was approximately computed as $\sqrt{2\delta}$, with $\delta(r) = \frac{r}{R}\frac{B_\phi^2 - \Lambda B_\theta^2}{B_0^2}$ and where Λ can be

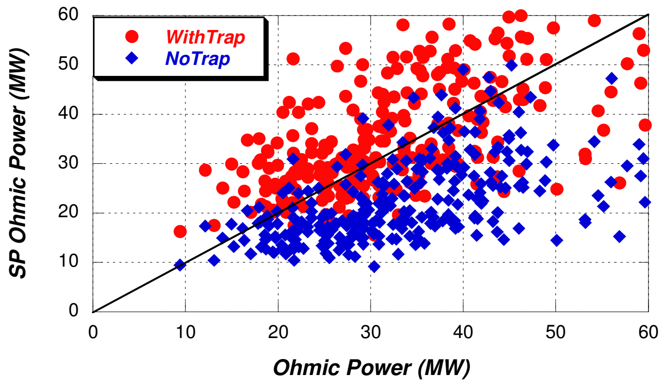

Figure 1: Comparison between experimental and Spitzer evaluation of Ohmic input power with and without trapped particle contribution.

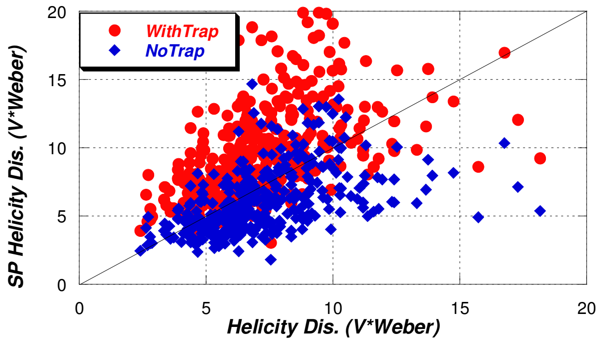

Figure 2: Comparison between experimental and Spitzer evaluation of helicity dissipation with and without trapped particle contribution.

computed solving at first order the toroidal equilibrium.

When this correction is included, the agreement between measured and computed (Spitzer) ohmic power improves as shown by red dots in Fig.1. It is important to note that the particle fraction estimation done is not fully consistent with the experimental kinetic profiles since it does not take into account the influence of collisions; this could explain the small average overestimation given by the red dots in Fig. 1.

In RFP plasmas, when the resistivity is not negligible, the magnetic helicity K defined as:

$K = \int_V \mathbf{A}\cdot\mathbf{B}dV - \phi\psi_c$, where ϕ is the toroidal flux inside the plasma and ψ_c is the external poloidal flux linked to it, can be dissipated and a new balance between injected and dissipated helicity can be written as: $\int_V \eta\mathbf{J}\cdot\mathbf{B}dV = \phi V_{loop} - \frac{1}{2}\frac{dK}{dt}$.

The comparison between the helicity dissipation computed from Spitzer resistivity and the measured input helicity is shown with and without the inclusion of the trapped particle effect in Fig. 2.

3. Transient effects

Terms like the magnetic energy derivative present in formula (2) can play an important role in discharges where transient effects are found to be very relevant. This is for example the case of pellet injection (strong time dependence of pressure profile), or discrete dynamo events and Oscillating Poloidal Current Drive operations (strong time dependence of magnetic profiles). A correct evaluation of ohmic power in these conditions is more challenging since the knowledge of time dependent profile evolution is required. To face the problem in the best possible way, we used temperature profiles from a recently implemented multichord double filter diagnostic instead of Thomson scattering ones. For the same reason, the magnetic equilibria were re-calculated for each time sample consistently with the measured pressure profile

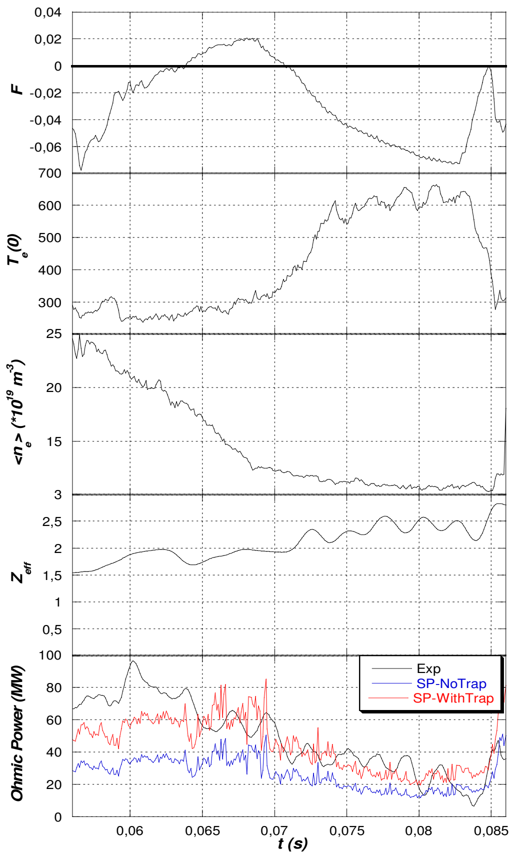

Figure 3: Transient simulation of ohmic power during an OPCD (#24057).

evolution.

In Figure 3 three evaluations of P_{Ohm} are compared together with the most relevant plasma parameters involved for an Oscillating Poloidal Current Drive pulse. Again, a better agreement is found between the experimental determination and the Spitzer one when the effect of trapped particles is included. In these cases the correspondence between computed and measured values better validate the correctness of all the elements involved in the computations.

4. Conclusions

Global balances based on both ohmic power or helicity dissipation are compatible, within experimental errors, with measured loop voltage in optimized RFX-mod discharges. No 'anomalous' terms affecting the loop voltage seem to be required to sustain RFP configuration. Experimental data confirm that trapped particles play an important role on the plasma conductivity also for high temperature RFP devices.

References

[1] K. F. Schoenberg and R. W. Moses, Jr., Phys. Fluids **27**, 1671 (1984)

[2] P. Sonato et al., Fusion Eng. Des. **66**, 161 (2003)

[3] V. Antoni et al., Nucl. Fusion **26**, 1711 (1986)

[4] H. Hutchinson, Principles of Plasma Diagnostics, 2nd edition, Cambridge University Press, New York 2002, p. 19.