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The effect of plasma turbulence on the plasma position reflectometry measurements at DEMO

31ST SYMPOSIUM ON FUSION TECHNOLOGY

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Introduction and overview

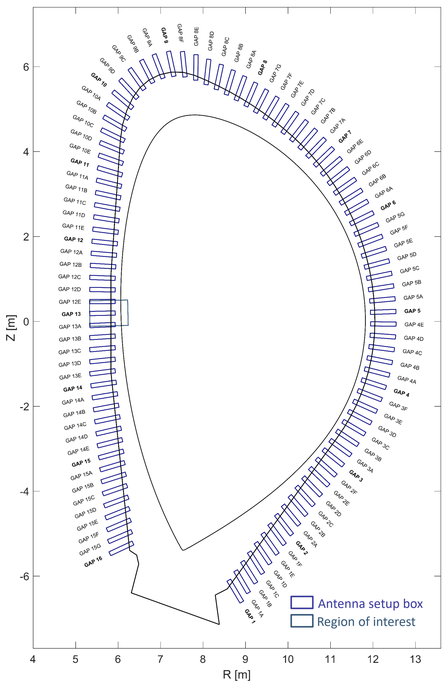
A variety of plasma diagnostics will be implemented on DEMO to provide the plasma state with necessary accuracy to the control system. In the present devices, the plasma position and shape are measured with the magnetic diagnostics. One of the major issues of its implementation in DEMO is the large integrator drifts that can occur during the long pulses due to the high levels of radiation [1]. This can lead to a wrong plasma position measurement, putting all the operation at risk.

The prime candidate to complement or substitute the magnetic measurements is Microwave reflectometry [1-2]. This diagnostic is capable of measuring electron density profiles in the edge. With the separatrix density is known, its position can thus be inferred [3]. This diagnostic is known by its reduced access, robustness and reliability, fulfilling the diagnostic requirements to the operation with the necessary resolution.

The DEMO Plasma Position Reflectometer

The DEMO plasma position reflectometer (DEMO PPR) consists in a system of multi-reflectometers distributed poloidally with the purpose of measuring the plasma position and shape. Since DEMO will operate in a pre-defined scenario, each reflectometer of the system can be optimized according to the expected parameters.

In this work we evaluate the effects of turbulence in the measurement performance of GAP13 (HFS) using REFMULF, a FDTD code for reflectometry simulations [4].



Measurements are influenced by:
- poloidal view
- emission angle
- antenna assembly
- operation plasma scenario
- any plasma deformation (plasma displacement, turbulence, etc…)

Previous studies:
- at least 15 measurements are required for a reliable [5] reconstruction of the separatrix
- the maximum number of measurements is limited by spatial constraints [5]
- 100 virtual positions were defined
- it has been shown that the error and the power can be optimized at each location [5]. Most of them are optimized aligning the emission perpendicularly to the separatrix.
- The system is stable for plasma displacements of 15cm, different scenarios and antenna assemblies

The effect of plasma turbulence

By sweeping the frequency and measuring the O-mode round-trip delay, the plasma density profile $[r(F), n(F)]$ is reconstructed with

$$r(F) = \frac{c}{2\pi^2}\int_0^F \frac{\partial\varphi}{\partial f}(F^2 - f^2)^{-1/2} df \qquad n(F) = (2\pi)^2 \frac{m_e \varepsilon_0}{e^2} F^2$$

This model assumes a plane wave being reflected in a density profile varying along the propagation direction. The simulations predict if the measurement error at the separatrix (accuracy of this model) is in the required range of [-1,1] cm.

$$E = \overbrace{r(F_{sep})}^{\text{simulation}} - \overbrace{r_0}^{\text{model}}$$

The turbulence affects the round-trip time delay and the received power. The plasma density is written in the form

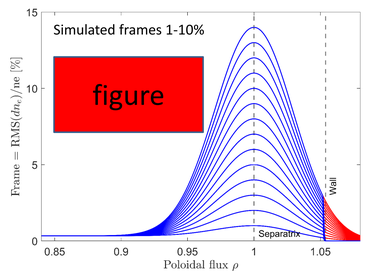
$$n_e(x,y) = n_0(x,y) + dn_e(x,y)$$

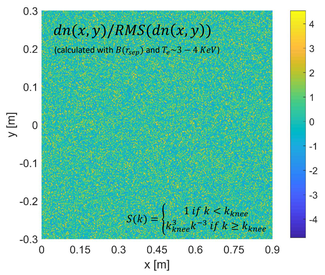
The turbulence is modulated with a Kolmogovov like spectrum S, using $k_{knee} = 1/\rho_s \sim 8\ cm$. The perturbation dn_e is defined as:

$$dn_e(x,y) = n_0(x,y) Frm(x,y) \frac{dn(x,y)}{RMS(dn(x,y))}$$

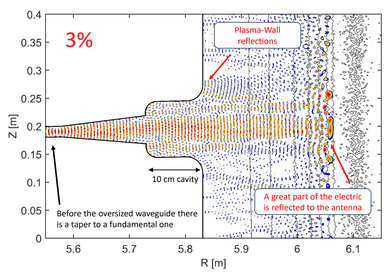
$$dn(x,y) = \sum_{i=1}^{i_M}\sum_{j=1}^{j_M} S(i,j)\cos[k_x(i)x + k_y(j)y + \overbrace{\phi(i,j)}^{\text{random}}]$$

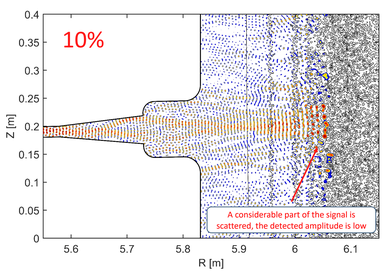
In this study we assume a frame centered at the separatrix, fixed spectrum and varying turbulence amplitude (1-10%).





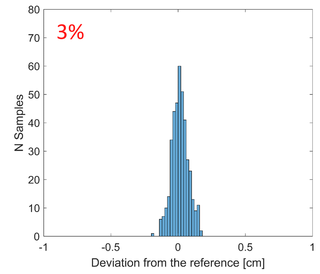
Simulation setup

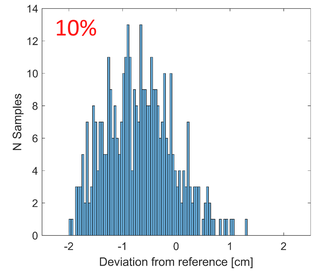


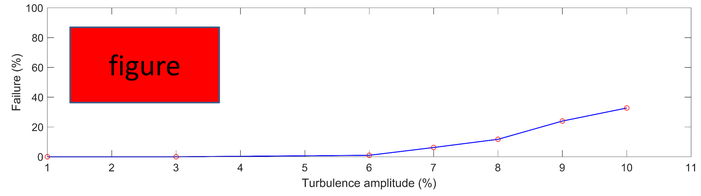


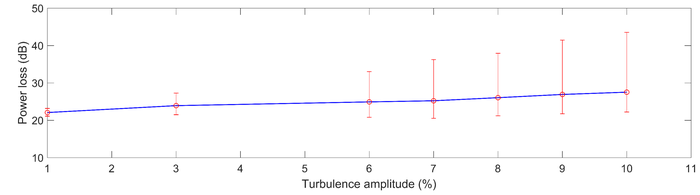
Results

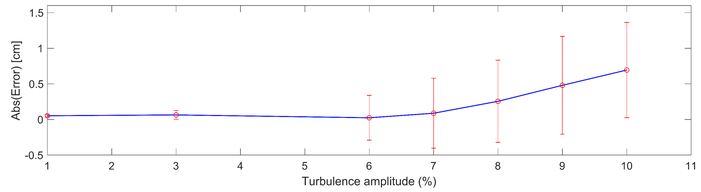
For each amplitude, 400 different turbulent plasmas were generated with a random spectral phase $\phi(i,j)$ profile. The obtained signals were analyzed using an automatized IQ detection method. The statistical analysis of the data describes the reliability of the reflectometer.











Future R&D

This study demonstrates the order of turbulence amplitude supported by the system before losing the position information or the signal in a plasma with similar characteristics. In order to prove the reliability of the entire DEMO plasma position reflectometer system, it is necessary

- to consider a higher number of samples to improve the statistics;
- to consider other spectrums of turbulence, including profiles from gyrokinetic simulations;
- doing the same procedure to the other positions of the system;
- to evaluate a more realistic power amplitude with 3D codes;

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