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Data Processing of Electric Probe Data Measured in TOKAMAKs

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1. Introduction

Langmuir probe diagnostics in tokamaks are very challenging, namely due to plasma fluctuations whose characteristic period is not much shorter than probe scanning-time. As a result, plasma parameters evaluation is usually constrained by the isotropic, Maxwellian electron energy distribution function (EEDF) assumption, probe diagnostics have been considered unreliable, EEDFs are not usually measured, and a huge amount of probe data has never been processed due to the lack of an appropriate numerical tool.

While results from all diagnostics are not cross-linked in order to gather complete information on how EEDFs change in time and space, a particular diagnostic cannot do much more than looking for "averaged" values. Yet, it is imperative that each diagnostic does not lose the precious time-dependence so that a complete, overall picture is achievable whenever possible.

In this paper we present results of a numerical procedure developed to minimize the effect of the above plasma fluctuations on EEDF evaluation from (I, V) probe characteristics measured in the edge plasma of the CASTOR tokamak. The procedure is based on adaptive, self-tuning filtering, which drastically eliminates (~ 40dB) fluctuation effects on the "average" without losing information on the fluctuation itself. In addition, model test results demonstrate that our error evaluation is a good likelihood parameter. Details on how EEDFs and plasma parameters are calculated can be found in the paper concerning P5.104 in this conference.

2. Filtering basics

Broadband noise and coherent disturbance effects can be readily minimized in probe characteristics intended for EEDF evaluation by filtering, a situation that drastically changes in case of close-to-coherent disturbances, namely when its characteristic period is not much shorter than probe sweeping-time, T, because standard Fourier techniques may fail when spectra are not discrete or when its components do not match an integer-order harmonic of $1/T$. Such is the case for magnetic field-induced instabilities, which ask for advanced techniques able to filter concurrent frequency and amplitude modulated disturbances superimposed on non-linearly time-varying signals, and to minimize distortion due to wide full-width at half-maximum (FWHM) filters.

In order to satisfy the above requirements we developed a PC program that processes data in the following way:

1) The (I, V) measured data is sorted, and interpolated in order to provide 1024 uniformly V-spaced bins.

2) A raw first derivative, dI/dV, is numerically calculated by convolution of the above data with the first derivative of an instrument function (IF), whose FWHM is adaptively chosen aiming for locally equal noise and error values. Noise is deduced from 3 adjacent data point 2nd derivatives [1], and error from a one-step algebraic reconstruction technique (ART) based on a deconvoluted form of Hayden procedure [2] as mentioned in [3]. As in previous works (see *e.g.* [4]), unless otherwise stated the IFs, $g(j)$, used here are Hann-like windows

$$g(j) = \frac{1+\cos(\pi j/n)}{2n}, \tag{1}$$

where n is the FWHM.

3) The characteristic period of disturbances is evaluated as the lowest value of τ ($0 < \tau < T/2$) that maximizes the function:

$$\int_0^{T/2} I(t) I(t+\tau) dt \Bigg/ \sqrt{\int_0^{T/2} I(t)^2 dt \cdot \int_0^{T/2} I(t+\tau)^2 dt} \; . \tag{2}$$

We found that the above autocorrelation-like procedure is more reliable than other methods we have tested, and the so calculated characteristic period is currently only used as a seed for the first point of the iterative process carried out in steps 5)-9) below.

4) The approximate value of the V-dependent, local period is deduced from Fourier transform techniques as being the window-size that maximizes the amplitude of the fundamental, hence approximate values of the COS and SIN component of the amplitude are calculated.

5) The first derivative of the disturbing signal amplitude is calculated.

6) The period of a dummy, amplitude modulated sinusoidal function matching the apparent period found in step 4) is calculated accounting for the above first derivative, and more accurate amplitude values are calculated accounting for the 2nd derivative, d^2I/dV^2, which is evaluated at step 8) during the previous loop.

7) dI/dV is filtered using the same FWHM that leads to a notch-filter for the dummy function.

8) d^2I/dV^2 is calculated from the filtered dI/dV achieved in the previous step.

9) The procedure loops back to step 5) until convergence is reached.

10) An additional ART is carried out to guess the error of the whole procedure.

11) An additional “cosmetic” filtering using a narrower FWHM IF may be included.

The correct operation of the filtering program was checked using a model test. In order to somewhat simulate probe characteristics measured in magnetized plasmas we used a 1st derivative given by the sum of

$$\left(\frac{dI}{dV}\right)_{target} = a\left(V_\mathrm{p} - V\right)e^{\frac{V-V\mathrm{p}}{b}} \qquad V \le V_\mathrm{p}, \tag{3}$$

with an amplitude and frequency modulated sinusoidal function (solid curve in Fig. 1).

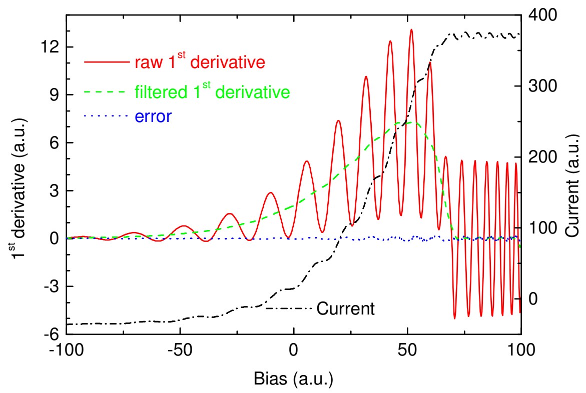

Figure 1: 1st derivatives: raw (solid) and after filtering (dash), guessed error (dot), and I (V) data (dash-dot) used in the model test.

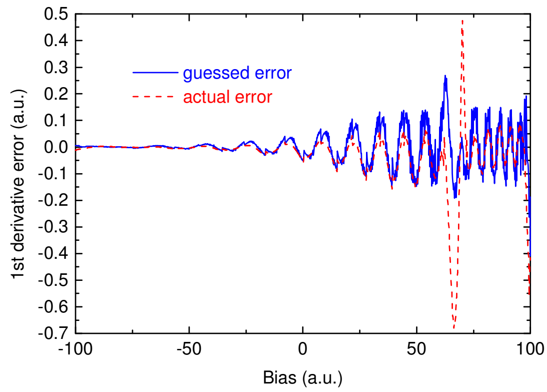

Figure 2: Model test errors: guessed (solid), and actual (dash) values.

The $I(V)$ data for program input was obtained integrating the above sum (dash-dot curve in Fig. 1). In Figure 1 we also present the achieved filtered 1st derivative (dash), and the guessed value of the error (dot). From Figure 2, where the guessed (solid) and the actual error (dash) are compared, we can see that our error evaluation is quite accurate, and that deviations can be expected only in the vicinity of very sharp 2nd derivatives (V_p = 70 a.u.).

3. Tokamak data

Results equivalent to those presented in Figure 1 are shown in Figure 3 for a real filtering situation case: CASTOR tokamak probe data (shot #26402, pin #1 of the rake probe, G7 measurement). Although we cannot present here the actual perturbation amplitude due to space limitations, readers can readily evaluate the above value by comparing the solid and the dashed lines in Figures 1 and 3, which clearly show that modulation deepness is about or above 100%, and that the modulation considered in the model case is very similar to the one found in the tokamak situation. Conversely, the range of period variation considered in the former case was made wider than in the latter in order to be sure that the program was able to detect and filter perturbations having a variable period. Such can be seen in Figure 4 where we show the period (normalized by the probe full span voltage) calculated by the filtering program at step 6) for the model test (solid) and for tokamak data (dot).

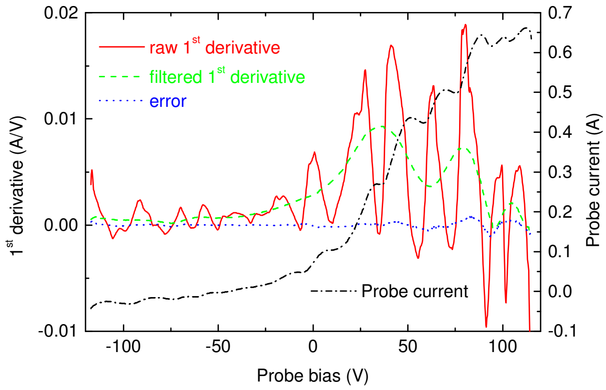

Figure 3: 1st derivatives: raw (solid) and after filtering (dash), guessed error (dot), and current (dash-dot).

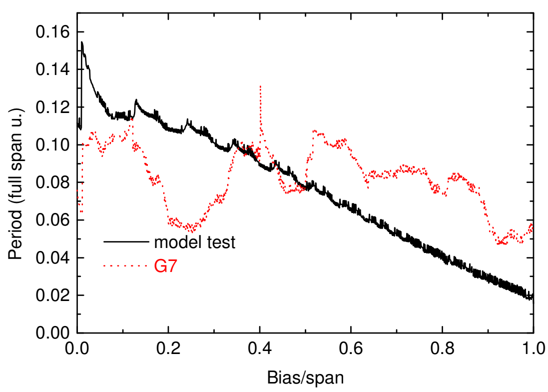

Figure 4: Normalized period: model test (solid), and G7 data (dot) (see text).

The EEDF and plasma parameters deduced from the current adaptive, filtering procedure are in close agreement with those from previous filtering schemes [5].

4. Conclusions

This work was intended to introduce the adaptive concept into tokamak probe data filtering in order to improve processing speed, and to enable an automatic choice of the filtering function FWHM values. In this first attempt we assumed that disturbances are locally described as amplitude modulated sinusoidal functions, whose amplitudes are linear, time-varying functions. In spite of such a rough assumptions, results are already quite acceptable, and can be achieved in a couple of minutes. A further increased filtering is required so that we can be absolutely sure that EEDFs can be assumed as steady within probe sweeping-time. Improving can be straightforwardly achieved changing the filter-function, including local frequency modulation, and the 2nd derivative of the disturbance amplitude. Yet, an increased processing-time will be unavoidable.

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