Status of correlation reflectometry analysis in JET

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Introduction

Turbulence measurements are essential to study transport in tokamak plasmas, which is often predominantly anomalous [Doyle 2007, Conway 2008]. In JET there are four X mode correlation reflectometry systems [Hacquin 2004] that can measure the radial correlation length and the level of density fluctuations. In the past, correlation reflectometry analysis in JET has focused mostly on the spectra of the reflectometer signals [Conway 2000]. With the upgrade of the microwave waveguides [Cupido 2005] and the consequent improvement in signal to noise ratio, reflectometer correlation lengths L are now being routinely calculated from the raw reflectometry data using the magnetic field from reconstructed equilibria and density profiles from the high resolution Thomson scattering diagnostic (HRTS) [Figueiredo 2008]. At present it is possible to draw physics conclusions by making qualitative interpretations of the reflectometer correlation length L and coherent reflection G to deduce trends in the turbulence level and in its true correlation length.

Results and Discussion

Modelling of correlation reflectometry in JET is required to obtain the actual turbulence correlation length $L_{\delta n}$ and level $\delta n/n$ from the reflectometer L and G [Kramer 2003]. Nevertheless, it is possible to make a qualitative interpretation of *variations* in L and G that is based on published simulations [Kramer 2003] and on the understanding of the interplay between turbulence level and reflectometer correlation length [Kramer 2003, Gusakov 2004]. To a variation of L corresponds more than just a variation of $L_{\delta n}$. For higher turbulence levels complicated interference patterns arise and the phase of the microwaves becomes increasingly chaotic and poorly localized [Mazzucato 1996]. Consequently, coherence is lost between the reflectometry signals from the two probing beams, which leads to lower values of L. Simulations in [Kramer 2003] show that, if G does not change too much, to a variation of L corresponds an opposite variation of $\delta n/n$. Coherent reflection G [Kramer 2003] is calculated

[*]See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008)

simultaneously with the correlation length [Figueiredo 2008]. The calculation of G is straightforward using $G = |\langle f(t) \rangle| \big/ \sqrt{\langle |f(t)|^2 \rangle}$, where $f(t)$ is the reflectometer signal. Unfortunately it is not currently possible to use this expression since it requires the DC components of the reflectometer signals that describe specular reflection [Mazzucato 1996, Gusakov 2004], which have not been made available. To circumvent this difficulty, and given the importance of coherent reflection not only to determine the fluctuation level but also the actual turbulence correlation length [Kramer 2003], coherent reflection is calculated in the frequency domain using the signal spectra $F(f)$ [Figueiredo 2008],

$$G(f) = |\langle F(f) \rangle| \big/ \sqrt{\langle |F(f)|^2 \rangle} = \langle |F(f)| \exp\{i\Phi_F(f)\} \rangle \big/ \langle |F(f)|^2 \rangle.$$

In this way some sensitivity to variations of the fluctuation level can be achieved at low, yet non-zero frequencies, of the order of tenths of kHz.

Figure 1 shows a typical output of the software tool that has been specifically developed for the analysis of data from the JET radial correlation reflectometer systems.

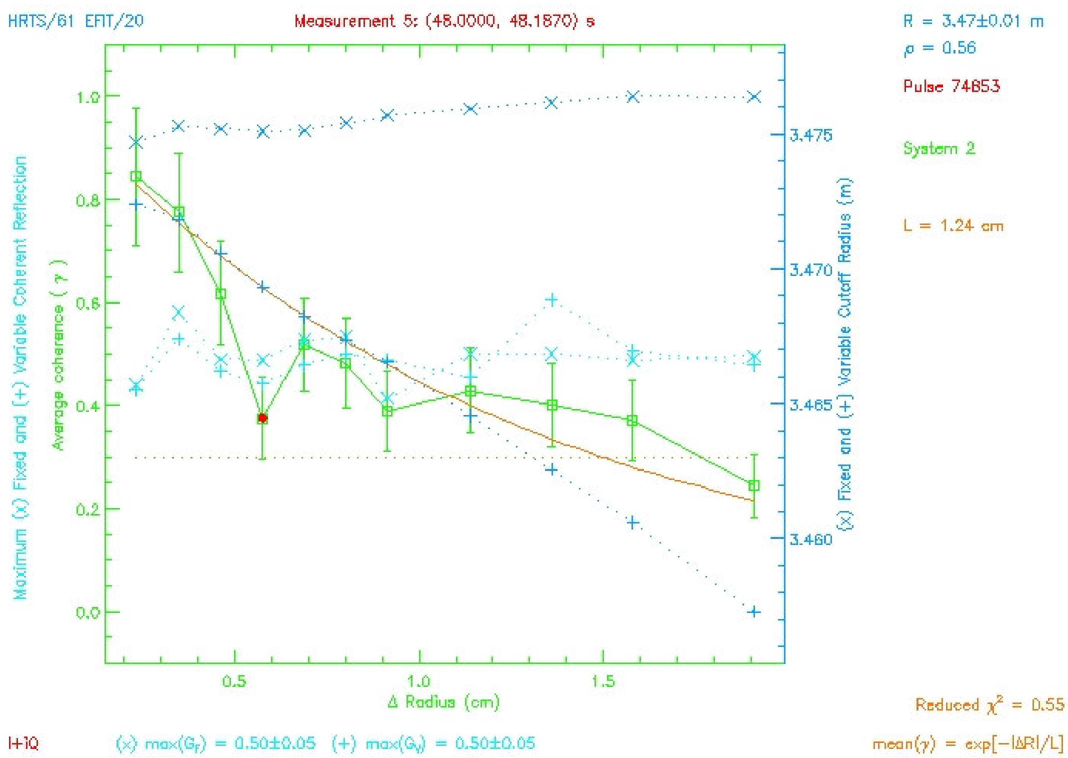
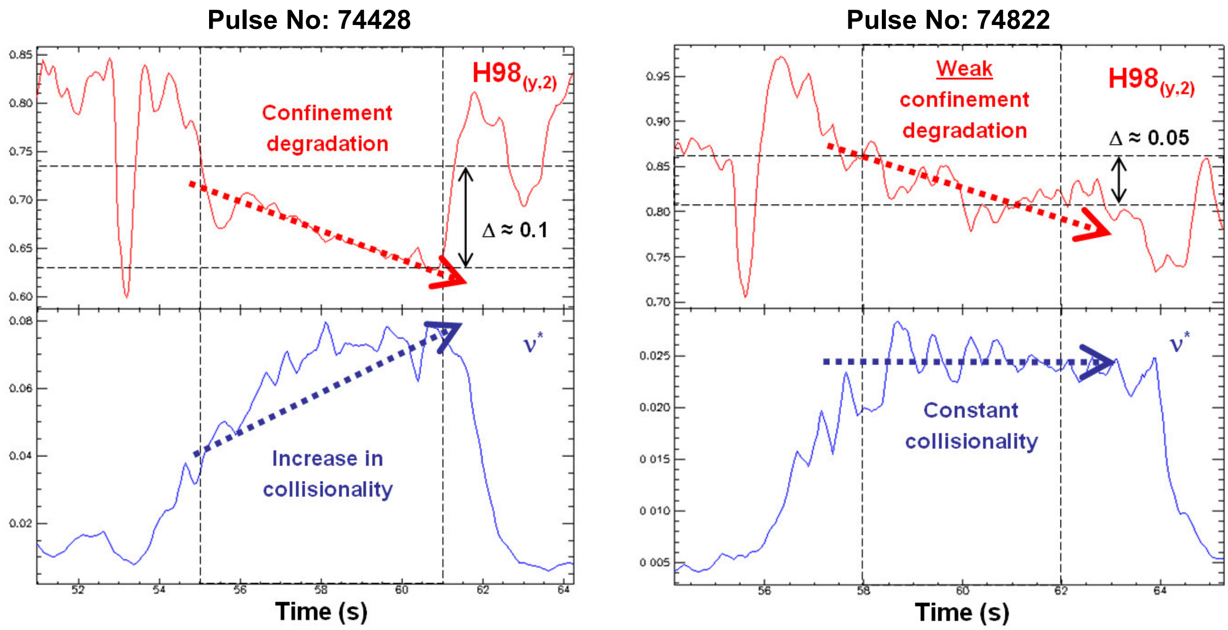


Figure 1. *Screenshot of the correlation analysis tool displaying a measurement made using data from reflectometer system 2 with 86 GHz fixed frequency during JET pulse #74853.*

Green points with error bars mark the coherence values for the variable frequency plateaus (left vertical axis), plotted versus the radial separation between the cutoff positions of the two beams. The orange line is a fit to the coherence points — the red coherence point has been excluded from the fit. The two cyan lines are the coherent reflection of the beams, whose average values during the measurement are shown in cyan on the bottom center. The blue lines (right vertical axis) are the cutoff positions of the two microwave beams. In blue on the top right is shown the average cutoff position during the measurement. In red on the top center the time range of the measurement (187 ms) is displayed. On the top left in blue there is information on the sources of density (HRTS) and magnetic field (EFIT) data. In orange on the right is the correlation length *L* and on the bottom right the coherence fit details used to retrieve *L*.

To exemplify the qualitative interpretation method, Figure 2 shows plots of the normalized confinement time $H98_{(y,2)}$ and collisionality ν^*, and a table with *L* values for two JET pulses. The basic principle is that confinement time should decrease with increasing collisionality (neoclassical transport) and core turbulence level [Durst 1993].



t (s)	Mode	L (cm)	R (m)
51	O	5.09	3.23
52	O	3.19	3.28
53	L	2.86	3.27
55	H	0.97	3.79
56	H	1.26	3.77
58	H	1.02	3.77
61	H	1.07	3.74

t (s)	Mode	L (cm)	R (m)
46	O	2.93	2.99
48	O	3.23	3.02
56	L/H	4.03	3.74
58	H	3.76	3.81
60	H	3.09	3.82
62	H	2.33	3.8
64	H/L	0.66	3.65

Figure 2. *For JET pulses #74428 and #74822 it is shown the time evolution of the normalized energy confinement time $H98_{(y,2)}$, collisionality ν^*, and the reflectometer correlation length L measured at radius R.*

In the case of pulse #74428 the degradation in confinement observed from 55 s to 61 s seems to be well correlated with an increase in collisionality, particularly until 58 s, whereas L values do not change significantly indicating that the variation in turbulent transport does not play a role. On the contrary, the slight confinement degradation in pulse #74822 from 58 s to 62 s appears to be correlated with decreasing L values, which corresponds to an increase in turbulence level. Notice that collisionality does not change significantly and L values are higher than in pulse 74428, which indicates a lower turbulence level.

Summary

Currently in JET, correlation lengths are being routinely calculated from raw radial correlation reflectometry data using a specially designed analysis tool. Although quantitative measurements require specific modelling, a *qualitative* interpretation of *variations* in the two reflectometer quantities correlation length L and coherent reflection G allows concluding on variations in turbulence level and correlation length. Correlations have been observed between variations in confinement, measured by the normalized energy confinement time; in the turbulence level, which is inferred from variations of the reflectometer correlation length at close radial positions; and in collisionality. After some calibration limitations are overcome and full-wave simulations performed, it will be possible to improve the current analysis and perform quantitative turbulence measurements using the existing correlation reflectometers.

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