28th IAEA Fusion Energy Conference (FEC 2020)

Contribution ID: **1012** Type: **Regular Poster**

# A phase-contrast-imaging core fluctuation diagnostic and first-principles turbulence modeling for JT-60SA

*Friday, 14 May 2021 12:10 (20 minutes)*

A core fluctuation diagnostic based on the phase-contrast technique[1] is being designed for the JT-60SA tokamak[2], with the assistance of a synthetic diagnostic coupled to a gyrokinetic code. This system will be able to resolve small-scale microturbulence as well as macroscopic fluctuations, with good spatial and temporal resolution, throughout the plasma cross-section and in all plasma regimes. The accessible wave-number range will cover the main ion-scale instabilities predicted to be at play, and optionally also the electron-scale ones. This diagnostic offers a unique opportunity to study turbulence, which is intimately tied to anomalous transport in tokamaks, for the first time in a truly reactor-grade device, and to help advance the knowledge base for ITER and DEMO.

The new superconducting tokamak JT-60SA, which is due to begin operating in 2020, will be the largest tokamak ever built and the most significant intermediate step in magnetic-confinement fusion before the inception of ITER operations. While the highest priority is currently assigned to preparations for first plasmas and commissioning activities, planning has already started in earnest for systems, and particularly diagnostics, to be added in the mid-2020's horizon for in-depth physics studies. The European contribution to the project, in particular, has already featured diagnostics for the initial phase and continues to foster contributions to these medium-term enhancements.

Among the European projects is the phase-contrast imaging diagnostic, now nearing the final design phase. The goal of this system will be the characterization of fluctuation dynamics at large, and the diagnostic is meant to be part of a core set that will be always operational in all scenarios. Plasma turbulence remains only partly understood even though it is deemed responsible for the greater part of anomalous transport, one of the most prominent limiting factors in reactor design. Additionally, larger-scale instabilities and oscillations, such as zonal flows, avalanches, streamers and MHD modes, all of which have significant effects on transport, will also be accessible for study.

Phase-contrast imaging (PCI) is a form of interferometry lacking an external phase reference, and relying instead on spatial filtering techniques to create interference between disparate momentum-space components of a single laser beam. The lack of an external reference makes the technique mostly unperturbed by mechanical vibrations and thus enhances its sensitivity. Interferometric techniques are inherently line-integrated; however, in a magnetized plasma the known properties of turbulence – namely its highly elongated structure along the field lines – can be used to localize the measurement with the aid of additional optical spatial filtering. This method is especially effective when the laser beam propagation is near-tangential to the toroidal magnetic field, as demonstrated on the TCV tokamak[3]. These properties, along with the lack of plasma cutoffs which renders PCI compatible with all regimes, result in a uniquely powerful technique.

The design of this diagnostic has been guided also by first-principles modeling of the microturbulence dynamics. Both linear and non-linear flux-tube gyrokinetic simulations have been performed with the GENE code, using the so-called scenario 1, a high $\beta$, double-null diverted plasma. An early finding of this analysis was that, unusually, electromagnetic effects cannot be ignored in this scenario. Indeed, linear simulations already reveal large contributions from electromagnetic effects, a likely harbinger of the landscape of future reactors such as ITER and DEMO. The CPU budget within the present study was insufficient thus far for fully converged nonlinear electromagnetic runs; such runs are being planned for 2020. The results of preliminary electrostatic simulations were processed through a synthetic diagnostic for the planned JT-60SA PCI diagnostic geometry, to generate simulated signals that can eventually be compared directly to traces recorded by the PCI detectors. Once these are Fourier-transformed in time and space, frequency and wave-number spectra are obtained. These are shown in Fig. 1 and are confirmed to lie well within the temporal and spatial bandwidth of the planned system[4]. The dominant modes here are found to be a mixture of ITG and TEM.

Indico rendering error

`Could not include image: [404] Error fetching image`

The diagnostic is envisioned to employ two ports in the equatorial port assemblies P8 and P1. As shown in Fig. 2, the two ports are not exactly symmetric, imparting a slight vertical inclination to the beam. It turns out that this choice is crucial to making the beam pass just inside, rather than just outside, the last closed flux surface on the high-field side of the torus. As spatial localization is greatest at that location (as well as near the magnetic axis), this choice results in a highly resolved measurement in the all-important edge pedestal region.

Indico rendering error

`Could not include image: [404] Error fetching image`

It should be noted that the beam crosses the plasma fully twice from the low- to the high-field-side edge, i.e., four times in terms of minor radius. As the spatial-filtering localization technique is based on magnetic-field topology, there is no guarantee that unique segments along the beam path can be selected, and indeed in most cases two separate segments are selected simultaneously – however, the chosen geometry causes these double segments to be projected on almost identical flux-coordinate values. Localization is thus well and truly achieved in terms of the flux-surface coordinate. Owing to very fundamental diffraction considerations, this localization is better at larger than smaller wave numbers. The calculated radial localization as a function of radius and wave number is shown in Fig. 3. (The functions are multivalued because of the multiple passes of the beam through the plasma.) At k=4 cm$\rho$, a resolution of 5% of the minor radius is achieved near the magnetic axis and near the plasma boundary, and of 25% at mid-radius.

Indico rendering error

`Could not include image: [404] Error fetching image`

In the concrete implementation of the diagnostic, it is envisioned that the light source and shaping optics, as well as the focusing and imaging optics and detection hardware, would be located on a platform to be situated above the torus and in close proximity to it. While this proximity will engender more stringent requirements for radiation shielding of equipment, the resulting simplification in the specification of the optical components appears worth the compromise.
The initial focus will be on Ion-Temperature-Gradient (ITG) and Trapped-Electron-Mode (TEM) fluctuations ($^{-1}$0.06-12), widely believed to dominate the contribution to anomalous transport. However, the diagnostic can be made fully compatible with measurements in the Electron-Temperature-Gradient (ETG) range. The diagnostic is expected to resolve fluctuations as small as $k\rho_i \sim$.
Experience on TCV and with previous applications (DIII-D, Alcator C-Mod, LHD) gives us high confidence in the feasibility of this diagnostic and in the likelihood of a successful implementation.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014–2018 and 2019–2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was supported in part by the Swiss National Science Foundation.

$\delta n/n \simeq 10^{-5}$ H. Weisen, Rev. Sci. Instrum. **59**, 1544 (1988)
[1] H. Shirai, P. Barabaschi, and Y. Kamada, Nucl. Fusion **57**, 102002 (2017)
[2] Z. Huang, S. Coda, and the TCV Team, Plasma Phys. Control. Fusion **61**, 014021 (2019)
[3] S. Coda, A. Iantchenko, K. Tanaka, and S. Brunner, 46th Conf. on Controlled Fusion and Plasma Physics, Europhysics Conf. Abstracts (Milan) **43C**, P1.1013

## Country or International Organization

Switzerland

## Affiliation

EPFL - SPC

**Primary authors:** Dr CODA, Stefano (EPFL - SPC); IANTCHENKO, Aylwin (EPFL - SPC); Dr TANAKA, Kenji (National Institute for Fusion Science); Dr BRUNNER, Stephan (EPFL - SPC)

**Presenter:** Dr CODA, Stefano (EPFL - SPC)

**Session Classification:** P7 Posters 7

**Track Classification:** Magnetic Fusion Theory and Modelling