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Synthetic diagnostics for fluctuation detection in toroidal plasmas

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It is important to make quantitative evaluation of turbulent transport with detailed comparison between experiments and simulations. Synthetic diagnostics use simulation data to represent experimental measurements by simulating measurement signals [1]. We have developed integrated Turbulence Diagnostic Simulator (iTDS) as a platform for synthetic diagnostics of magnetically confined plasmas [2]. iTDS is a framework for making global analyses in real magnetic geometries of fusion devices, and various analysis routines for several experimental diagnostics are developed on this platform. The way to utilize synthetic diagnostics for profile measurement of plasma fluctuations is discussed in this presentation. Here the focus is mainly set on a geometric effect from magnetic configurations.

iTDS connects global simulations and experimental observations. The analysis consists of the following processes;

i) 3-D simulation of plasma instabilities and transport

ii) Plasma device parameter set and adjustment of the data format (if necessary)

iii) Simulation to obtain signals by experimental diagnostics

In process i), several codes can be used to obtain 3-D plasma profiles and time evolution of fluctuations. Global codes are used for calculations in torus plasma geometries. In general, particular models do not always include all the necessary quantities, so lacked information is supplemented with other calculation or assumption, if necessary in process ii). In addition, spatial coordinates in simulation codes may be different with ones used for numerical measurement, so data transfer is necessary in that case. Data mapping to the common format is often used, but here we introduce the object-oriented method in accordance with each data format to gain the maximum information. The data transfer is limited to the minimum. Then the numerical measurements are carried out in process iii). The basic component to capture 3-D dynamics from simulation data is extracting the local value at the arbitrary position from discreet data by interpolation. The combination of this basic routine can give multi-point observation along a line of the sight of each diagnostic.

One example of the diagnostic simulations is heavy ion beam probe (HIBP) in LHD [3]. HIBP is powerful diagnostic to give information of several kinds of quantities, as plasma fluctuations and electromagnetic fields inside the plasma. Calculation of 3-D trajectory of heavy ions, including non-circular plasma shape and experimental arrangement of diagnostics, is carried out in iTDS. Mean radial and 3-D perturbation profiles of the potential are included in the 3-D magnetic configurations. The 3-D variation of the potential in LHD is calculated by global drift kinetic code FORTEC-3D, which is given by the neoclassical process [4]. The effect of the 3-D variations is evaluated to find out the observation points of HIBP. Variation of the beam energy (velocity of the heavy ions) and attenuation rate of the beam intensity give information of the plasma potential and density along the HIBP trajectory. The magnetic fields, electrostatic potential and electric fields (spatial derivatives of the potential) are used as the input, in which the set of the equations of motion is solved to calculate the trajectories. The sudden change of the effective potential at the ionization point gives difference of the energies between the injected and detected heavy ions, which gives observation of the potential value at the ionization point. The observation points depend on the injection conditions of the heavy ions, so the profile scan can be made. 2-D profile scan is also possible with change of the injected beam energy. Beam intensity includes effects of (1) damping in the primary and secondary paths, and (2) ionization rate at the ionization point, so comparison between the potential variation and beam intensity gives information on relative strength of effects (1) and (2).

The other example of the diagnostic simulations is phase contrast imaging (PCI) in JT-60SA [5]. Phase change of an injected laser beam occurs due to density fluctuations, which is measured by PCI to get wavenumber spectrum of density fluctuations. PCI measurements are simulated by combining magnetic field equilibrium calculations in the JT-60SA tokamak with fluctuation fields calculated by a gyrokinetic simulation code GENE [6]. Since the obtained signal is integrated along the line of sight, it becomes necessary to reconstruct local density fluctuation information from this signal. In the local signals, asymmetry in the wavenumber spectrum is observed, reflecting the tilt of the magnetic field lines. These variations in fluctuation components suggest possibility to distinguish local information from the integrated signal by using the magnetic field direction. Comparison with the local wavenumber spectrum at each measurement position gives the information how the wavenumber spectrum of the integrated signal is composed of a combination of signals from different positions.

In this way, turbulence diagnostics can be carried out with real magnetic geometries of fusion devices in iTDS.

References

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