§18. New Developments in Neutral Particle Diagnostic Data Analysis on LHD

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Measurements of kinetic energy distributions of neutral atoms escaping from the plasma are used on LHD as a method to investigate the ion component distribution function $f_i(\mathrm{v}, \vartheta, \mathrm{t})$ and its evolution due to the application of various heating schemes. Statistical and analytical methods have been developed that enable the neutral particle energy spectra obtained by passive measurements to be recalculated into f_i reflecting the kinetic effects, the single particle confinement properties depending on the particular magnetic configuration, the finite β effects such as MHD induced fast ion losses, radial electric field effects, etc. A calculation scheme required for local active pellet charge exchange (PCX) diagnostic data processing has also been developed.

(a) Statistical data analysis. Ideally, the charge exchange neutral particle diagnostic experimental data is a set of M arrays (E_1, …, $E_{N(j)}$) of neutral particle energies measured at a certain observation angle during M sequential time intervals, and $N(j)$ is the total number of particles collected during the jth time interval. This form of data is achievable with solid state detectors by using pulse height analysis techniques, while the other analyzers, e.g. $\vec{E} \parallel \vec{B}$ ones, intrinsically form a histogram of the incoming particle energies over a certain number of histogram bars called "energy channels". The empirical probability density function $f_n(\mathrm{E})$ of neutral particle energies is to be calculated from the experimental data so as to satisfy a specified precision criterion. The obtained function is then to be used to calculate the ion distribution for further analysis.

The simplest histogram or frequency polygon approach has been typically used so far in experimental practice, when the automatically built $f_n(\mathrm{E})$ is a piecewise linear function. As an improvement of the neutral particle diagnostic statistical data analysis, the empirical probability density estimators and kernel smoothing techniques [1] have been applied for the calculation of a smooth function $f_n(\mathrm{E})$ from the experimental data to a preset precision requirement.

(b) Neutral Particle Source Localization. A numerical method has been developed that can be used to estimate the source of neutral particles within a helical plasma column as a function of the magnetic surface [2]. The method is applicable to the data analysis of passive line-integral diagnostics of escaping neutrals. The magnetic surface structure taken from magnetohydrodynamic equilibrium calculations defines the kernel of the integral equation. A regularized solution is obtained over a discrete grid by minimizing the appropriate objective functional. The corresponding linear system is solved in terms of least squares using QR algorithm. The reconstructed radial dependence provides additional information for comparisons and cross-checks using the localized active diagnostic data.

The method does not take into account the angular dependence of the neutral particle source function. This is often the case due to the anisotropy of the ion distribution function influenced by neutral beam injection or ion cyclotron radiofrequency heating. If the angle between the diagnostic observation direction and the magnetic field varies significantly along the line of sight within the plasma, the local neutral particle source function reconstruction may become a much more complicated task. The angular distribution of suprathermal alpha particles produced in nuclear fusion reactions is, however, isotropic.

The method has been tested for LHD geometry. The obtained regularized solutions are close to the predefined test profiles and the curve smoothness is achieved by choosing an appropriate regularization parameter. The reconstructed radial dependence provides additional information for comparisons and cross-checks using the localized active diagnostic data.

(c) Ion Distribution Calculation Scheme for PCX. The application of a diagnostic based on PCX method using a compact neutral particle analyzer (CNPA) on LHD for localized measurements of energy resolved fluxes of fast neutrals escaping from a polystyrene $(\text{-}C_8H_8\text{-})_n$ pellet ablation cloud was reported in [3]. The experimentally obtained neutral particle energy spectra should be corrected for the energy-dependent "neutralization" rate in order to calculate the ion distribution function. The energy-dependent Poisson exponent $e^{-\tau(E)}$, i.e. the neutral flux attenuation factor should also be taken into account. For PCX diagnostic data analysis, the equilibrium H^0 neutral fraction $F_0(E)$ has been calculated for polystyrene $(\text{-}C_8H_8\text{-})_n$ and Li pellet ablation clouds by using a more complete scheme of atomic collision processes taking place in the cloud than that used in [3].]. In particular, in addition to charge exchange reactions, the ionization of hydrogen atoms by cloud plasma and impurity C^{q+} ions has been taken into account, determining the high energy behavior of $F_0(E)$.

The plasma "optical depth" $\tau(E)$ describing the loss of fast hydrogen atoms on their path from the pellet cloud to the analyzer has been estimated [4] taking into account the effect of He^{2+}, C^{6+}, O^{8+} and Fe^{26+} impurities. The analytical approximation of the atom loss cross-section [5] has been used. This function is required for both passive and PCX data processing.

References

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