CONFERENCE PRE-PRINT

THE ESTABLISHMENT OF THE SYNTHETIC DIAGNOSTIC MODELLING SPECIFICALLY FOR THE IMAGING NEUTRAL PARTICLE ANALYZER ON EAST

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Abstract

In fusion research, the diagnostics of key information from fuel particles are various and intersecting. To obtain the information about particles more accurately and thoroughly, the synthetic diagnostic method is applied to establish a physical diagnostic model and develop a complete forward simulation for imaging neutral particle analyzer (INPA) on Experimental Advanced Superconducting Tokamak (EAST). Correspondingly, the results are compared and analysed with the experimental data. It is proved that the active signals of the numerical simulations can be obtained by this method and the main discrepancy between simulated active signals and experimental data is the passive signals induced by the loss particles. The establishment of this synthetic diagnostic greatly promotes the analysis of INPA signals and provides a powerful help for further study of the behaviours of fuel particles by obtaining more information on fast ions through INPA.

1. INTRODUCTION

A series of diagnostic technologies for critical information on fuel particles, mainly including neutron emission spectroscopy (NES), γ-ray spectroscopy (GRS), collective Thomson scattering (CTS), fast-ion D_α spectroscopy (FIDA), and neutral particle analyzers (NPA), cover different physical quantities and sensitive ranges of parameters, but they overlap.

The integrated analysis of multiple diagnostic data makes it effective to combine different diagnostics to obtain accurate and comprehensive information on fuel particles. The synthetic diagnostic method is the basis to achieve it, being a forward simulation analysis method that synthesizes diagnostic data by combining predictive numerical simulations of plasma with diagnostic physical models. The range of parameters sensitive to diagnosis and information about the distribution function of particles can be estimated through this method.

INPA, this diagnosis, has first proposed and employed on DIII-D [6], and has its unique advantages compared with traditional NPAs, being small in size and getting intuitive images which make the behaviours of energetic ions visualized.

This paper focuses on the INPA on EAST [1] and establish the synthetic diagnostic modelling for it, providing the basis for further studies using this diagnostic approach.

2. MODELLING AND SIMULATION

For INPA (the detailed setup of the INPA on EAST is elaborated in Ref. [1]), the fast ions in the specific area of phase space, after the charge exchange with the neutral particles in the tokamak, are neutralized and may enter the lines of sight of the INPA and thus be detected. Then, inside the INPA diagnostic device, the particles undergo a series of interactions, such as being re-ionized by the carbon foils, being deflected by the magnetic field, and hitting the scintillator screens. For this whole process, a physical diagnostic model is established and a complete forward simulation is developed.

Based on the processes described above, the physical model of this diagnostic is established similar to the simulation idea of the INPA on DIII-D [2]. Detailed, as shown in FIG. 1, first, with the measured temperature and density profiles, the fast ion distribution functions under neutral beam injection (NBI) heating scenarios are calculated by NUBEAM module of TRANSP; then, according to the obtained fast ion distribution functions, combined with the specific data of the neutral beam geometry, the magnetic fields, and the INPA geometry, FIDASIM [3][4][5] (a Monte Carlo code used to calculate the signals generated by the charge exchange between ions and neutrals, mainly for FIDA and NPA diagnostics) is applied to calculate the neutral flux reaching the INPA head; finally, a newly developed programme describes the INPA instrument response, including the interaction of the particles with the foils, the full orbit path of the particles when they deflected by the magnetic field, and the luminescence and camera response, so the striking points and the final synthetic image are obtained. It is worth noting that this model only includes the process of active charge exchange (the charge exchange between ions and neutral beams), and it does not consider the process of passive charge exchange (the charge exchange between ions and other neutral particles), but actually the active signals are the dominant ones.

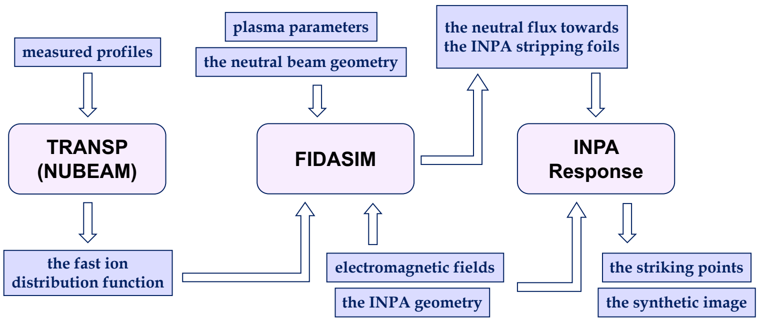


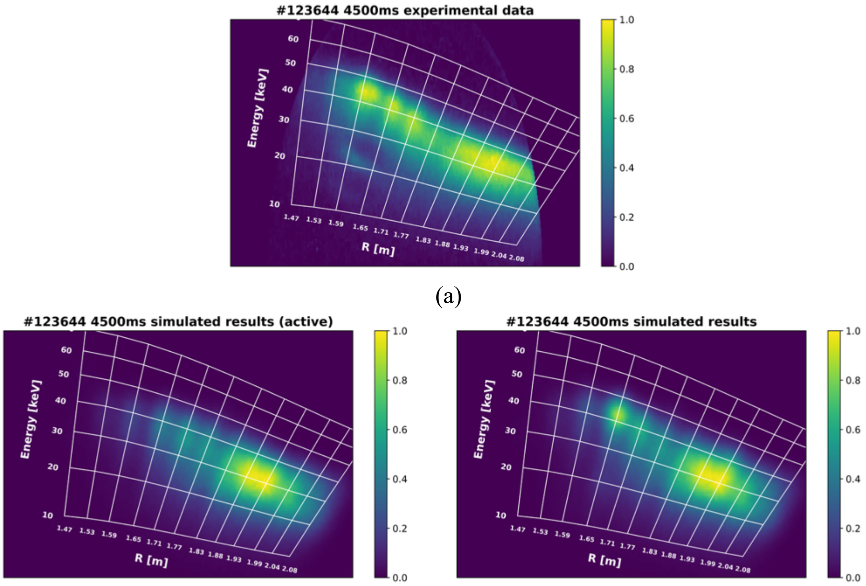
FIG. 1. The flow chart of the forward simulation for the active INPA signals on EAST.

3. RESULTS AND DISCUSSIONS

3.1. Simulated Results

As mentioned in the previous section, the diagnostic physical model is established, thus an active forward simulation method is developed. Take EAST discharge 123644 as an example. In this discharge, NBI 1L and 2L are turned on, where 1L is the active beam, i.e. providing a background of neutral donors for charge exchange. The selected time is 4500 ms, which is approximately one second after the beams are turned on. The results are shown in FIG. 2. The experimental image (FIG. 2(a)) and the active signals simulated by the synthetic diagnostic method (FIG. 2(b)) are presented, both of which are two-dimensional distribution maps, taking the tokamak radius R and the particle energy E as horizontal and vertical axes. Fluxes under specific R values are fluxes of different lines of sight.

It shows that the particle distribution at $R = 1.8 - 2.1$ m is in good agreement with the experimental situation; correspondingly, it can be speculated that the active signals dominate the lines of sight for $R > 1.8$ m. But the three lines of sight between $R = 1.59 - 1.71$ m have obvious signal spots that do not appear in the simulation and might be come from passive charge exchange.



(a)

(b) (c)

FIG. 2. The INPA experimental image (a), the synthetic active signals (b), and the synthetic signals (the active parts and the passive parts induced by the loss particles) (c) for EAST discharge 123644 at 4500 ms.

3.2. Passive Signals Induced by the Loss Particles

In order to find out the source of the signals at $R = 1.59 - 1.71$ m, which is very localized in fast ion phase-space, the time evolutions of signals in different discharges have been analysed. It is proposed that these signals come from a faster process than the slowing-down of fast ions and come from beam 1L (the active beam).

Beside the analysis of time evolutions, simulations are used. The ASCOT simulation of the first orbit loss of the particles from beam 1L shows that the loss locations (FIG. 3) are close to the lines of sight of the INPA head. Then the results are input into FIDASIM and INPA Response. The final simulated spots at these lines of sight (FIG. 2(c)) confirm that it is the loss particles from beam 1L, which undergo the charge exchange with the neutrals on the edge (i.e. a kind of passive signals). Thus, the main discrepancy between the experimental results and the simulated active results is illustrated as the passive signals induced by the loss particles with a ring asymmetry, and this phenomenon has also been observed in other discharges.

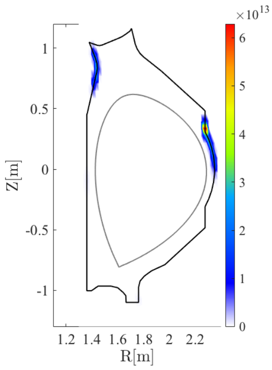


FIG. 3. The R-Z location distribution of the loss particles from beam 1L within 0.1 ms at 4500 ms, calculated by ASCOT.

4. CONCLUSION

In summary, it has been shown that the synthetic diagnostic method and modelling can obtain the numerical simulation signals of the active charge exchange of INPA, which are consistent with the experimental results in the lines of sight which active signals dominate. Moreover, the main discrepancy between the experimental data and the simulated active results is illustrated as the passive signals induced by the loss particles.

The completion of this work provides ideas and a basis for analysing INPA data and obtaining more information through INPA. Further, it will help solve key problems for fusion reactor fuel particle diagnostics, that is, how to scientifically design diagnostic systems to better cover the intervals of key parameters and how to integrate the interrelated complex diagnostic signals.

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