6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Design of the stripping unit and the electromagnetic analysis unit for the E//B NPA on HL-2A/2M tokamak

Linge Zang[1], Yufan Qu[1], Yuan Luo[1], Weiping Lin[2]
[1] Center for Fusion, Southwestern Institute of Physics, [2] Institute of Nuclear Science and Technology, Sichuan University
e-mail (speaker): zanglinge@swip.ac.cn

A neutral particle analyzer (NPA) detects the atoms of hydrogen isotopes escaping from the plasma. In a high temperature plasma like ITER, the escaping atoms are produced in three main neutralization processes: (1) charge exchange with the background hydrogen isotope neutrals, (2) radiative recombination of the protons (deuterons, tritons) with the electrons and (3) electron capture from (or charge exchange with) the hydrogen-like impurity ions. Process (1) is only dominant in the energy range of 20–50 keV. Beyond 50 keV, processes (2) and (3) play significant roles in the neutralization. At 200 keV the neutralization rate of the electron captured from He^+ and the radiative recombination is almost one order higher than the charge exchange with D^0 and T^0. The cross sections for the charge-exchange reactions of fast triton in higher energy range are shown in figure 5 of reference [1]. An E//B NPA has both energy and mass resolutions. In LHD device, it measures the flux of fast neutrals with different energies [2], enhancing the understanding of fast ion behavior [3]. In the future device like ITER, E//B NPA will be applied to measure the D/T fuel ratio [4]. The high-energy particle fluxes of D and H are measured on JET tokamak during ICRF heating experiment with an E//B NPA [5]. The density ratio of D and H are measured on LHD with an E//B NPA [6]. The NPA counting rate is simulated for D and T on ITER [4].

A tandem type E//B NPA is under development for the fast ion measurement on HL-2A/2M tokamak. This article discusses the design of the analyzer, similar to that described in references [7] and [8]. The analyzer parameters are matched to the conditions of its use on the HL-2A/2M tokamak and the purpose of fast ion measurement. This NPA is capable of H and D resolution, and the energy range is set to 10–200 keV for both H and D. The beam injector on HL-2A could inject D of 30–50 keV. The beam injector (positive source) on HL-2M could inject D up to 80 keV and H up to 50 keV. A negative-ion-source neutral beam is under developed, the upper limit of the energy range for which is 200 keV for both D and H. However, the current plan is that only positive source beams will be installed on HL-2M. The upper limit of the energy range for this NPA is set to 200 keV because in the previous plan the negative-ion-source neutral beam will be installed on HL-2M. The lower limit is set to 10 keV because this NPA is built for fast ion diagnosis instead of ion temperature measurement. As a contrast, the energy range of CNPA in reference [9] is 0.8–80 keV for hydrogen and 0.8–40 keV for deuterium, and the energy range of CNPA in reference [10] is 64–968 eV. Both the CNPAs in [9] and [10] have covered the energy range for ion temperature measurement. As shown in figure 1, the NPA system in this work includes a gas stripping unit, an electromagnetic analysis unit and a two dimensional detector array. An NPA can use either a gas stripping unit or a foil stripping unit to ionize fast neutrals. However, a foil could lose its thickness or even be damaged due to the bombardment of the fast particles in long time run. The NPA described in this paper uses a gas stripping unit to avoid the replacement of the stripping unit. The stripping unit is composed of a stripping room (equipped with two differential tubes and a gas supply bellows), a vacuum chamber and a vacuum pumping system. The stripping efficiency of the stripping room is calculated in the form of global efficiency $R \times f_{+1}$, where R is the non-scattered-away rate and f_{+1} is the fraction of charge state +1. The magnetic field of the E//B analyzer is produced with a permanent magnet. The yoke and the poles of the magnet are made of mild steel and the magnet plates is made of NdFeB. The magnetic poles are specially designed to focus the ion trajectories and increase the use rate of the magnet. Shape of the magnet and the electric plates are carefully designed so that the ions are dispersed into two lines of H+ and D+ on the detector plane. For each line, the energy increases from 10 to 200 keV from one side to another, as shown in figure 1.

References

[1] Afanasyev V I et al, Plasma Phys. Rep. 36 659 (2010)
[2] Kamio S et al, Nucl. Fusion 60 112002 (2020)
[3] Heidbrink W W and Sadler G J Nucl. Fusion 34 535 (1994)
[4] Afanasyev V I et al, Plasma Phys. Control. Fusion 55 045008 (2013)
[5] Afanasyev V I et al, Rev. Sci. Instrum. 74 2338 (2003)
[6] Ozaki T et al Plasma Fusion Res. 15 2402034 (2020)
[7] Chernyshev F V et al, Instrum. Exp. Tech. 47 214 (2004)
[8] Mezonlin E D et al, Rev. Sci. Instrum. 78 053504 (2007)

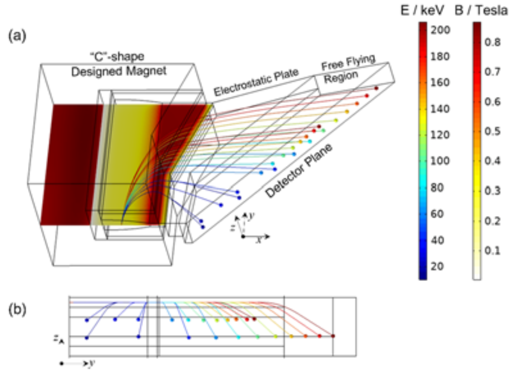

Figure 1. Simulation result with COMSOL. (a) The magnetic field strength and ion trajectories in the analysis unit, (b) the ion striking points on the detector plane.