§68. Perpendicular and Tangential Angular Resolved Multi-Sight (ARMS) Neutral Particle Analyzer System in LHD

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ARMS-NPA is based on PSD. AXUV (20-segments) as the detector is a commercial product and is reliable as the ultra-violet or soft-X-ray detector in current mode. In principle, the response for the particle (hydrogen atom) is similar to that for soft-X-ray because it is a semi-conductor detector. Therefore proper energy resolution can be expected if the particle flux is limited and the bias is adjusted in the counting mode. The hard X-ray is not strong at helical plasmas except the electron cyclotron heating (ECH) plasma. Ultra-violet, soft X-ray and visible light can be protected by thin Aluminum film of 0.1-micron thickness. The energy loss in Al film is considered by the calculation.

The preamplifier is attached directly with the detector. The minimum observable particle energy of 15 keV is determined by the electrical noise level. The detector and preamplifier are cooled by the liquid nitrogen to reduce the electrical noise. ARMS has been installed after the calibration by using Americium 241 gamma-ray source. The size of ARMS is only 15 cm-diameter and 30 cm length by using the combination with the compact pre-amplifiers circuit and the small detector. ARMS has a time resolution of 5 ms (1024 time frames), an energy resolution of several keV (2000 energy channels) and large dynamic range for the particle flux and the flexible viewing angle. The flux is limited by the piezo slit in order to avoid the saturation of the signal and to obtain the wide dynamic range. Two ARMSs, which are installed with perpendicular and tangential views on 9-O port in LHD, are operated at the same time. Those observable pitch angles on the magnetic axis in LHD are 70-100 (perpendicular) and 90-140 (tangential) degrees, respectively. Perpendicular ARMS can also measure the vertical or 2-dimentional profile of the neutral flux by using the rotary mechanism. The data are acquired by CAMAC-PHA (Clear Pulse Co.) and WE-7000 (Yokogawa Co.), and are immediately analyzed just after the discharge. In the long discharge on the LHD, there is a capability to obtain the real time, energy/time resolved pitch angle distributions during discharge.

The experiments have been performed at ECH, five neutral particle injections and the ion cyclotron resonance heating (ICH) plasmas. Tangential NBI#1 and #3 are injected normally to tangential ARMS but tangential NBI#2 is injected to tangential ARMS by the backscattering. (Perpendicular ARMS is the opposite direction) Perpendicular NBI#4 and 5 are completely same specification.

The potential (radial electric field can be obtained by negative gradient of the potential) is monitored by Heavy Ion Beam Probe (HIBP). HIBP can be operated only at weak and positive magnetic field (=co-direction with the plasma current). In any case, perpendicular NBI#4 has been applied to the tangential NBI plasma. The data are plotted by the circular polar coordinates. The radial direction, the declination and the color show the particle energy, the pitch angle (angle between the magnetic axis and the sightline of ARMS) and the flux in logarithmic scale, respectively. The white lines show the energy range of 15 keV, 30 keV and 45 keV. The data are accumulated during 0.25-0.5 seconds. The magnetic field is written in each figure.

Trapped particles (=high pitch angle component), which come mainly from perpendicular NBI and from scattered component of tangential NBI, are well confined even if at the low magnetic field. This is the advantage of the helical device. The particle loss around 80 degrees are decreased by increasing the absolute value of the magnetic field.

In the passive charge exchange measurement, the signal has line-integrated and no radial information. Therefore the comparison between the simulation and the experiment is necessary. The background neutral and the particle orbit are calculated by the Aurora code and GNET code, which had been developed by S.Murakami, respectively. We compare two cases of perpendicular NBI#4 and tangential NBI#1 plasmas measured by the tangential ARMS. On the high magnetic field, the neutral particle distribution in the perpendicular NBI#4 plasma is uniformly distributed due to the ion-ion collision in this energy range. In the simulation, the expected neutral particle distribution is agreed with the experimental result. In the tangential NBI#1 plasma, the result is qualitatively agreed with the simulation. The tangential component with low pitch (transit particle) in the simulation is smaller than that in the experiments. Some of the transit particles escape from the last closed magnetic surface (LCMS) but re-enter to the plasma again. However in the GNET, the calculation region is limited within LCMS. The experimental result may show that the re-entering ion cannot be negligible.

The comparison of neutral particle distributions, have been performed when the magnetic axis is shifted. In the perpendicular NBI plasma, we can find that the total flux and the uniformity are decreased when the magnetic axis is shifted to the outward. In the tangential NBI#1 and/or NBI#3 plasmas, the confinement of the transit particle becomes worse. The center of Poincarè map of the transit particle orbit is about at Rax=3.6 m in any magnetic shifts. Therefore the part of the particle orbit is outside from the plasma at the outer magnetic axis.

The ICH of 38.4 MHz is overlapped to the NBI plasma. In ICH plasma, the rabbit-ear structure around the pitch angle of 70 degrees can be expected because there are many trapped particles at the tip of the banana orbit. K. Saito, et al., measured them by scanning system of the TOF-NPA shot-by-shot. However ARMS can observe them only on discharge.

The data of the tangential ARMS during the NBI plasma intermittently overlapped the ECH are shown. Eight frames of every 0.5 seconds accumulation are shown. At the second frame, the much flux and the uniform distribution can be obtained because only ECH is applied in the low-density plasma. At the fourth frame, the high pitch angle component remains due to the back scattering particle from the NBI#2 when the NBI#1 and NBI#2 are applied. At the fifth frame, the high pitch angle component is recovered when the ECH is overlapped. At seventh frame, the perpendicular component is completely disappeared when only NBI#3 is applied. At last frame, the high pitch angle component is strongly recovered due to the application of ECH. In this discharge, the potential has been monitored by HIBP. The time history of the potential profiles is shown. The symbol colors correspond to the arrow colors. During ECH application, the electric field (negative potential gradient) is positive because the electron escapes from the plasma. At this time, the high pitch angle component is well confined due to the positive electric filed.