(4) High Energy Beam Technology

High energy beams are used in various fields of magnetic field confining nuclear fusion research. Neutral hydrogen/deuterium beam is commonly used for plasma heating, current drive, and diagnostics such as charge exchange recombination spectroscopy (CXS) and beam emission spectroscopy (BES). Heavy Ion Beam Probe (HIBP) is another diagnostic tool using high energy beam. These tools are also used in LHD, and the successive development on the beam formation system or improvement of the diagnostic system is undertaken through the collaborations. Among them, the activities on the development of NBI system are reported here. Those of diagnostics (BES and HIBP) are reported in other category of this annual report.

In LHD, neutral beam injection (NBI) is a main plasma heating source as in other helical devices and tokamaks. NBI is also utilized as plasma production, which is a unique feature of LHD assisted by the fact that the confining magnetic field exists in steady state. The neutral beam is also used for measurement of ion temperature and velocity profiles via CXS, and the induced current can be used to change magnetic field configuration for MHD studies under the week magnetic field strength.

The very specific feature of LHD NBI systems is that most of them are negative-ion based injection systems. Production of negative ion beam is an advanced technology to make high energy neutral beam (>1MeV) that can be applicable for ITER and future reactors. In LHD, the maximum injection energy of hydrogen beam is 180 keV, which is even too high to construct an injection system based on conventional positive-ion technology because the neutralization efficiency is so small. The negative ion technology is still in the course of development. Therefore, the R&D activity continues in NIFS as well as other institutes such as JAEA, Max-Planck Institute and CEA Cadarache.

A new NBI was introduced in 2006 which is a low energy (40keV), positive-ion based hydrogen beam injector for CXRS. The specific feature of this beamline is that the injection angle is normal to the LHD plasma. The choice of beam angle was done judging from the successful results of ICRF heating in the case of inner-shifted discharge of LHD, and it is true that the normally injected beams are confined well. The spatial profiles of ion temperature can be obtained well by CXS, and new phenomena was also found for the transport of carbon ions (impurity hall).

The report-1 "Further Development of Neutral Beam Injection Power in the 11th Campaign" by Takeiri et al. is a summary of the injected beam power of three negative-ion based NBI's (N-NBI) and a positive-ion based NBI in LHD through the 11th experimental campaign in FY 2007. As for N-NBI, the total input power of 16MW was achieved, which exceeds the specific value for the first time. As for P-NBI, the maximum port through power of 8MW was achieved, which also exceeds the specific value by 33%. As a result, the total injection power was increased and 22MW was recorded.

Four reports are on the basic study to improve large negative ion sources for plasma heating.

The report-2 "Optical Observation of Cesium Spectra in a Hydrogen Negative Ion Source at 20 Seconds Beam Operation" by Ikeda et al. is on the behavior of cesium neutrals and ions in the arc plasma of negative ion source of BL-3. It was found that the light emission of Cs neutral as well as Cs ions near the plasma grid increases during negative ion beam extraction for 20 seconds, where the acceleration current was almost constant. This fact suggests that it is not Cs in plasma that determines the negative hydrogen current density.

The report-3 "Caesium-deposition in the large area negative ion source for LHD-NBI" by Oka et al. is on the measurement of Cs atom flux by using deposition monitor which is a quartz crystal transducer with a fast shutter. It was shown that there is a critical shutter opening time (-0.5s) above which detected flux reduced during arc discharge. This was not found after the arc discharge was terminated.

The report-4 "Characteristics of Electron Beam Behavior in Negative-Ion Accelerator" by Jiang et al. is on the numerical study on the electron extraction acceleration in the accelerator of negative hydrogen ion source. For this sake, the commercially available simulation software "MAGIC" has been used, which is an electromagnetic, relativistic, particle-in-cell code widely used in plasma and particle beam studies. In the simulation, the whole volume is filled with low density of hydrogen gas. It is clearly shown that the produced electrons and ions via ionization are accelerated in both directions, and their orbits do not diverge much.

There are several R&D's on production of ions (both negative and positive) and beam formation;

The report-5 "Relation of H- extraction and plasma potential structure in a hydrogen negative ion source" by Matsumoto et al. is to discuss the electrostatic potential effect on the extraction efficiency of negative ions in the arc plasma. It is studied by both experimental and numerical studies that extraction field makes a potential hill in the plasma which hinders the transport of negative ions to the extraction grid.

The report-6 "Characterization of High-Density Helicon Plasma Source for Negative Ion NBI" by

Shinohara et al. is on the study of dense plasma source produced by helicon wave, which can also be used as a unit source for constructing a large ion source. The high-density helicon plasma production (~ 10^{13} cm^{-3}) with ~ 1 kW rf power was successfully established using a compact, very strong magnetic field device (up to 10 kG), changing gas species(Ar and Xe), rf frequency (7 and 14MHz) and the magnetic field (640 to 3040G).

The report-7 "Development of Antenna System for High Power rf Ion Source" by Shoji et al. is on the development of multi-antenna RF plasma source. The size of plasma chamber is 35cm x 35cm x 20cm. Using the antenna which consists of four parallel copper pipes inserted into quartz tubes and is placed in SUS Faraday shield cage. With RF power of 200kW the ion saturation current of 150mA/cm^2 was obtained at the gas pressure of 1.5 mTorr.

The report-8 "Beam Current and Focal Point Evaluation of a Strongly-Focusing High-Intensity He^+ Ion Source Developed for Fusion Produced Alpha Particle Diagnostics" by Kobuchi et al. is on the development of high convergence helium ion source for alpha particle diagnostics. The profile of the beam was measured by IR camera seeing a 2-D temperature profile on a carbon plate target. The focusing of the beam was evaluated by the dependence of half-width of the beam on the distance from the ion source.

(Kaneko, O.)

List of Reports

1. "Further Development of Neutral Beam Injection Power in the 11th Campaign," Takeiri Y. (NIFS)
2. "Optical Observation of Cesium Spectra in a Hydrogen Negative Ion Source at 20 Seconds Beam Operation," Ikeda K. (NIFS)
3. "Caesium-deposition in the large area negative ion source for LHD-NBI," Oka Y. (NIFS)
4. "Characteristics of Electron Beam Behavior in Negative-Ion Accelerator," Jiang W. (Nagaoka Univ. of Technology)
5. "Relation of H- extraction and plasma potential structure in a hydrogen negative ion source," Matsumoto Y. (Tokushima Bunri Univ.)
6. "Characterization of High-Density Helicon Plasma Source for Negative Ion NBI," Shinohara S. (Kyushu Univ.)
7. "Development of Antenna System for High Power rf Ion Source," Shoji T. (Nagoya Univ.)
8. "Beam Current and Focal Point Evaluation of a Strongly-Focusing High-Intensity He^+ Ion Source Developed for Fusion Produced Alpha Particle Diagnostics," Kobuchi T. (Tohoku Univ.)