(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 (CXRS) 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 CXRS, 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 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 and CEA Cadarache.

A new NBI was introduced last year 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 Ti have become available by CXRS without doping impurities such as Ar or Ne. Therefore the injection power has been doubled this year.

The report-1 "Operation Summary of Neutral Beam Injection Systems in the 10th 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 10th experimental campaign in FY 2006. As for N-NBI, the total input power of 13.8MW was achieved, which is the record of the system. In the first beamline, the maximum port through power of 6MW was achieved. It should be noted also that high power level of more than 10MW was available throughout the experimental campaign. The reproducibility of the second beamline was improved.

Three reports are on the performance of large negative ion sources.

The report-2 "Improvement of Beam Optics in the Accelerator with Multi-Slot Grounded Grid" by Tsumori et al. is on the performance of new accelerator in the negative ion source of BL-1, which has a multi-slot grounded grid (MSGG). The optics of the grid system was improved by shaping the apertures of extraction grid, and the optimum condition of extraction-acceleration voltage ratio was performed. As a result, good transparent efficiency was obtained, and the largest port-through beam power was attained.

The report-3 "Optical Emission Spectroscopy in Large Negative Ion Source for LHD-NBI" by Ikeda et al. is on the behavior of cesium neutrals and ions in the negative ion source of BL-3. It was found that the correlation between the good beam divergence and the amount of cesium. It was also found that the amount of Oxygen impurities decreases as the cesium increases. The consumption of cesium becomes large in the case of long pulse operation compared with the repetitive short pulse operations.

The report-4 "Spectroscopic Observations of Beam and Source Plasma Light for LHD-NBI Large Area H^- source" by Oka et al. is on the measurement of energy distribution of the beam by using Doppler shift of H-alpha line emitted from the beam. As the number of segments increases, the width of observed shifted peak becomes broad, which comes from the result that the angles between the beam and the line of sight is different from segment to segment. The origin of energy spread may also come from the stripping of negative ion during acceleration.

The report-5 "Electron-Beam Control and Efficiency Improvement for Negative-Ion Accelerator" by Jiang et al. is on the numerical simulation of extracting negative ions from the plasma using the geometry of accelerator used in the negative ion source of LHD NBI. The specific feature of this condition is that the electrons are also extracted. In the extraction grid, the electron deflection magnets are inserted to avoid electrons from entering to the acceleration region. The simulation shows that some of the secondary electrons from the extraction grid enter into the acceleration, which may cause the heat load on the ground grid.

The report-6 "Up-grade of positive-ion based Neutral Beam injector for perpendicular injection on LHD" by Osakabe et al. is on the upgrade of low-energy perpendicular beam line which is a conventional positive-ion based NBI. Adding two more ion sources with in-vessel components and power supplies, The port-through power was increased more than twice (3MW to 7MW). The excess of gas inflow into the LHD vacuum chamber was also reduced after this upgrade.

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

The report-7 "The role of an electric field for H^- extraction in a hydrogen negative ion source" by Matsumoto et al. is on the study of the relation between the negative ion density in the ion source and the amount of extracted beam. It was found that the observed negative ion current is much larger than the prediction of Monte Carlo simulation. One of the effects attributing to this enhancement is the electric field formed around the extraction hole.

The report-8 "Development 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. Using Ar gas, high density plasma of 10^{19} m^{-3} was obtained with input RF power of 1kW, and for Xe $2.7x10^{19}$ m^{-3} was obtained with 0.5kW. An optimum magnetic field strength was observed.

The report-9 "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 four antennae system, the dependence of extracted positive ion current on the antenna position was studied. The first experiment of extraction of negative ion was done.

The report-10 "Development of a Strongly-Focusing High- Intensity He^+ Ion Source for Fusion-Produced Alpha Particle Diagnostics" by Shinto et al. is on the development of high convergence helium ion source for alpha particle diagnostics. The goal is to focus 3A helium beam into 3cm in diameter about 75cm downstream from the ion source. The size of extraction area of the ion source is 10cm in diameter. Because very short focal length is required, concave grid system are adopted. The extraction of the beam is successful, and 3A of drain current was obtained at the acceleration energy of 20keV. The performance of the beam will be investigated.

The report-11 "Development of a RF driven compact Au^- source for local electric potential measurement of the LHD plasma" by Wada et al. is on the development of RF driven plasma sputtering type negative gold ion source for heavy ion beam probe system, which is expected to have long life time. One of the requirements for the RF ion source is to reduce operating gas pressure, and initial test result showed that the pressure becomes below 0.1Pa as the RF power increases.

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List of Reports

1. "Operation Summary of Neutral Beam Injection Systems in the 10th Campaign," Takeiri Y. (NIFS)
2. "Improvement of Beam Optics in the Accelerator with Multi-Slot Grounded Grid," Tsumori K. (NIFS)
3. "Optical Emission Spectroscopy in Large Negative Ion Source for LHD-NBI," Ikeda K. (NIFS)
4. "Spectroscopic Observations of Beam and Source Plasma Light for LHD-NBI Large Area H^- source," Oka Y. (NIFS)
5. "Electron-Beam Control and Efficiency Improvement for Negative-Ion Accelerator," Jiang W. (Nagaoka Univ. of Technology)
6. "Up-grade of positive-ion based Neutral Beam injector for perpendicular injection on LHD," Osakabe M. (NIFS)
7. "The role of an electric field for H^- extraction in a hydrogen negative ion source," Matsumoto Y. (Tokushima Bunri Univ.)
8. "Development of High-Density Helicon Plasma Source for Negative Ion NBI," Shinohara S. (Kyushu Univ.)
9. "Development of Antenna System for High Power rf Ion Source," Shoji T. (Nagoya Univ.)
10. "Development of a Strongly-Focusing High- Intensity He^+ Ion Source for Fusion-Produced Alpha Particle Diagnostics," Shinto K. (Tohoku Univ.)
11. "Development of a RF driven compact Au^- source for local electric potential measurement of the LHD plasma," Wada M. (Doshisha Univ.)