XA9745749

PRESENT STATUS OF RESEARCH ACTIVITIES AT THE NATIONAL INSTITUTE FOR FUSION SCIENCE AND ITS ROLE IN INTERNATIONAL COLLABORATION

J. FUJITA
National Institute for Fusion Science,
Nagoya, Japan

Abstract

In the National Institute for Fusion Science (NIFS), Japan, a helical magnetic confinement system named Large Helical Device (LHD) is under construction with objectives of comprehensive studies of high temperature plasmas in a helical system and investigation of a helical reactor as an alternative approach.

Superconducting coils of $l = 2$, $m = 10$, major radius $R = 3.9$ m, produce a steady state helical magnetic field for confinement, together with poloidal coils on LHD. The magnetic field strength on the axis is 3.0 T in the phase I and 4.0 T in the phase II experiment. The plasma major radius of LHD is 3.75 m, and averaged plasma radius is 0.6 m. The plasma will be produced and heated with ECH, and further heated with NBI and ICRF. It is also planned to produce a steady state plasma in LHD. It is expected to have the first plasma in 1998. Small devices such as CHS and others are under operation in the NIFS for supporting the LHD project. The Data and Planning Center of NIFS is collecting, compiling and evaluating atomic and molecular data which are necessary for nuclear fusion research.

The talk will include the present status of the construction of LHD, research activities on the development of heating and diagnostic devices for LHD, and experimental results obtained on CHS, JIPP T-IIU and other devices. The role of NIFS on promoting IAEA activities to bridge large scale institutions and small and medium scale laboratories for world-wide collaborations in the field of plasma physics and fusion research will also be introduced, together with an idea of organizing a regional center in Asia.

1. Introduction

The nuclear fusion research is a long term project. It is necessary to gather every possible brains from all over the world to realize a fusion reactor. A flexible strategy, not only along the tokamak line, but also with a variety of alternative approaches is necessary, with close international collaboration.

Based on these considerations, the main research activity in the National Institute for Fusion Science (NIFS), Japan, has been directed towards the study of plasma confinement and heating in a helical system, as a complementary approach of tokamak research to the comprehensive understanding of magnetically confined toroidal plasmas. For this purpose, a helical device called Large Helical Device (LHD) is being constructed at a new site in the city of Toki [1, 2]. The JIPP T-IIU tokamak and the Compact Helical System have produced important experimental data to support the LHD project. Super computers are used for large scale plasma simulation as a powerful tool to understand physical phenomena in plasmas.

Among various activities at NIFS, diagnostic developments for LHD will be a typical example which bridges the works on the large scale device and those on small devices. These activities, together with some of experimental results obtained on JIPP T-IIU and CHS will be explained in the following.

2. The LHD Project

The physics subjects of the LHD project is summarized as follows:

1) Produce a high $n\tau T$ currentless plasma and study transport problem in order to obtain basic data which can be extrapolated to a reactor grade plasma.
2) Realize a high β plasma of averaged beta value higher than 5 % which is necessary for a reactor plasma and study related physics.
3) Install divertor and obtain basic data necessary for steady state operation through experiments of controlling quasi-stationary plasmas.
4) Study behavior of high energy particles in a helical field and make simulation experiments of alpha particles in reactor plasmas.
5) Make a complementary study of tokamak plasmas to widen and deepen the comprehensive understanding of magnetically confined toroidal plasmas.

The target plasma parameters for the study of above subjects are settled under three operation modes:

1) High $n\tau T$ mode: $T_i = 3$ - 4 keV, $n_{av} = 10^{20}$ m^{-3}, $\tau_E = 0.1$ - 0.3 s, $B = 4$ T.
   $n\tau T > 10^{20}$ keV m^{-3}s ($Q \sim 0.35$).
2) High T_i mode: $T_i(0) = 10$ keV, $n_{av} = 2 \times 10^{19}$ m^{-3}, $B = 4$ T.
3) High β mode: $\beta > 5$ %, $B = 1$ - 2 T.

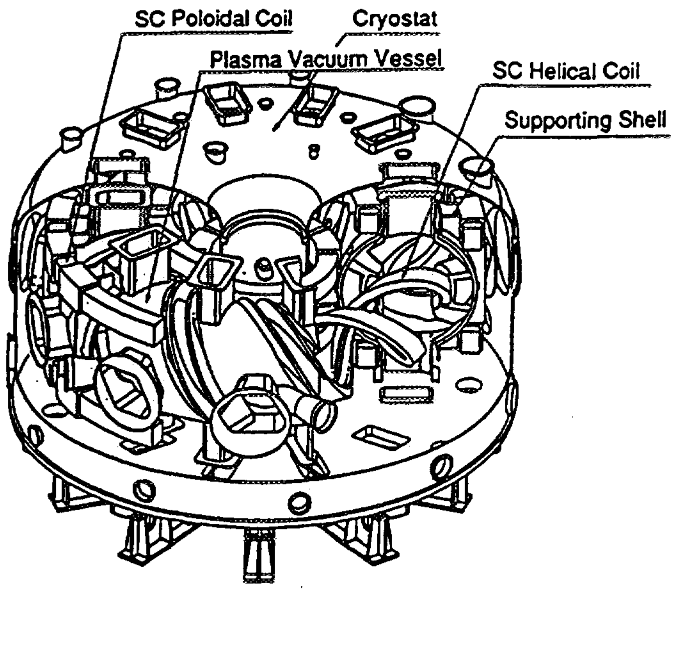

Fig. 1. A conceptual drawing of LHD

Table 1. Machine parameters of the Large Helical Device (LHD) under construction at NIFS.

Parameter	Phase I	Phase II
Major radius (m)	3.9	3.9
Coil minor radius (m)	0.975	0.975
Averaged plasma radius (m)	0.5 - 0.65	0.5 - 0.65
Plasma aspect ratio	6 - 7	6 - 7
l (pole number)	2	2
m (pitch number)	10	10
Plasma volume (m^3)	20 - 30	20 - 30
Magnetic field		
Center (T)	3	4
Coil surface (T)	6.9	9.2
Helical coil current (MAt)	5.85	7.8
Coil current density (A/mm^2)	40	53
Liquid helium temperature (K)	4.4	1.8
Plasma duration (s)	10	10
Repetition time (m)	5	5
Heating power		
ECRH (MW)	10	10
NBI (MW)	15	20
ICRF (MW)	3	9
for steady state operation (MW)	--	3
Neutron yield (n per shot)	--	2.4×10^{17}

The machine parameters of LHD is summarized in Table 1. Superconducting coils of pole number $l = 2$, pitch number $m = 10$, major radius $R = 3.9$ m, produce a steady state helical magnetic field for confinement, together with inner and outer vertical coils, and shaping coils. The pitch modulation which is employed in LHD brings a better helical symmetry and clear helical divertor structure. It is designed so that the magnetic field configuration can be changed as flexibly as possible for a variety of experiments.

Because the helical coils are wound continuously around the machine, the windings are being carried out on site instead of constructing the device in the factory and transport it to the site. The helical coils are cooled with a pool-boiling manner, while the poloidal coils of cable-in-conduit type are forced-flow cooled. The whole machine is set in a large cryostat. The construction will take more than two years from now, and will be completed in the end of 1997. A conceptual drawing of LHD is shown in Fig. 1.

Table 2. List of Diagnostics for LHD.

Diagnostics	Purpose	Descriptions
Magnetic Probes	I_p, plasma pressure, position and shape of plasma	Rogowski, Mirnov, Flux loops
Microwave Interferometer	$n_e l$	2mm/1mm wave, single channel
FIR Laser Interferometer	$n_e l\ (r)$	119 μm-CH_3OH laser, 10-channel
Microwave Reflectometer	n_e, *ne* fluctuation	under development
Thomson Scattering	$T_e\ (r)$. *ne* (r)	200 spatial points
ECE	$T_e\ (r, z)$	2-D imaging
X-ray Pulse Height Analysis	T_e, impurities	20-ch Si (Li), 4-ch Ge detectors
Neutral Particle Analyzer	$T_i, f\ (E)$	radial scan
Charge Exchange	$T_i\ (r),\ V_p\ (r)$	use of diagnostic neutral beam
Spectroscopy / Polarimetry	$q\ (r)$	
X-ray Crystal Spectroscopy	$T_i\ (r)$	0.1-4 nm, $\lambda/\Delta\lambda$:10^4
Neutron Diagnostics	neutron flux, T_i high energy particles	NE-213 detectors, ^{3}He counters, activation foil
Bolometers	$P_{rad}\ (r)$	metal film, silicon diode, pyroelectric detector
VUV Spectroscopy	impurities, T_i	1 - 200 nm, $\lambda/\Delta\lambda$: 10^4
Visible Spectroscopy	n_0 (H), Z_{eff}	200 - 700 nm, $\lambda/\Delta\lambda$: 5 x 10^4
Langmuir Probes	T_e, n_e	Fast scanning and fixed probes
Visible/Infrared TV	plasma position, PWI wall/limiter temperature	TV systems
Soft X-ray Diode Array	MHD Oscillations	silicon surface-barrier diodes
MW/FIR Laser Scattering	microinstabilities	1 mm/195 μm multichannel
Heavy Ion Beam Probe	plasma potential, fluctuation	Au^+ or Tl^+, 6 MeV, 100 μA
Diagnostic Pellet	particle transport	Hydrogen/Double layer ice pellet, C, Li
High-energy Particle Diagnostics	high-energy particles	Li / He beam (2 MeV, 10 mA) probe, particle detector probes

3. Plasma Diagnostics for LHD

Although LHD is not a tokamak but a helical system, the diagnostics for LHD are not much different from those for tokamaks. The essential difference from a tokamak is that the plasma shape has no axial symmetry, and an elliptic plasma cross-section rotates poloidally along the magnetic axis. Then, 3-dimensional diagnostics should be provided for LHD. Moreover, the plasma should be diagnosed through long and narrow observation ports which are drilled across the cryostat. Therefore, the diagnostics for LHD have various features different from those in conventional tokamaks. On the other hand, it is an advantage of helical system to have no center pole or windings of the transformer, so that inboard observation ports are available on LHD.

It is also planned to produce a steady state plasma in LHD. A proper function of divertor is vitally important in a long pulse machine. Special caution should be taken in the design of divertor diagnostics. However, the divertor diagnostics are still in a phase of under development.

Although no D-T operation is planned on LHD, the D-D operation will produce a significant amount of neutrons. Major parts of diagnostics are placed in adjacent rooms or underground of the main experimental hall, which are biologically shielded with thick concrete walls.

The diagnostics which are in preparation for LHD are summarized in Table 2. Many of these diagnostics utilize the results of developments achieved on the supporting machines, JIPP T-IIU and CHS. Among a number of diagnostic developments, that of a heavy ion beam probe (HIBP) will be explained as an example.

4. Development of Heavy Ion Beam Probe

The plasma potential profile, or radial electric field distribution, is an important quantity to be measured in a helical system, because it is strongly related to the plasma confinement properties. Although the measurement of poloidal rotation speed is utilized to find the radial electric field, a direct method to obtain the potential distribution is necessary.

A heavy ion beam probe has been designed for the potential profile measurement on LHD [3 - 5]. Because of a large size of the plasma and a high magnetic field intensity on LHD, a heavy ion beam such as gold should be accelerated as high as 6 MeV for the beam to penetrate the plasma, even at the magnetic field intensity of 3 T in the first phase. Due to non axi-symmetric configuration of helical magnetic field, the injected beam does not remain in a toroidal plane, but traverses both in toroidal and poloidal directions. The same is for the secondary beam. As a consequence, the secondary beam comes out from the observation port located toroidally next to the beam injection port. A schematic drawing of HIBP system for LHD is shown in Fig. 2.

For accurate measurement of plasma potential and its fluctuation, the beam should have an energy spread as small as possible. From this viewpoint, a gold negative ion source of plasma-sputter-type has been developed [6]. Negative ions thus produced are accelerated in a tandem manner, and converted into positive ions through a stripping gas cell which is at the high voltage end. A test stand has been constructed for studying negative ion production, extraction, energy dispersion and charge stripping efficiency. An energy analyzer of a high resolution and of high voltage characteristics is also being designed.

On JIPP T-IIU, a 500 keV HIBP system is operating. As an interesting result, a plasma potential change associated with the sawtooth crash has been observed.

As a prototype of the HIBP system for LHD, a 200 keV system has been constructed and applied to CHS. A unique idea of active trajectory control method is confirmed to work on this system.

5. International Collaboration

The promotion of international collaboration is one of the important roles of NIFS. The diagnostic development is a good example of the collaborative work. A basic idea will come out from any small laboratory or from individuals. The idea can be tested using a small device before constructing an actual equipment for a large device. At the same time, this kind of work will

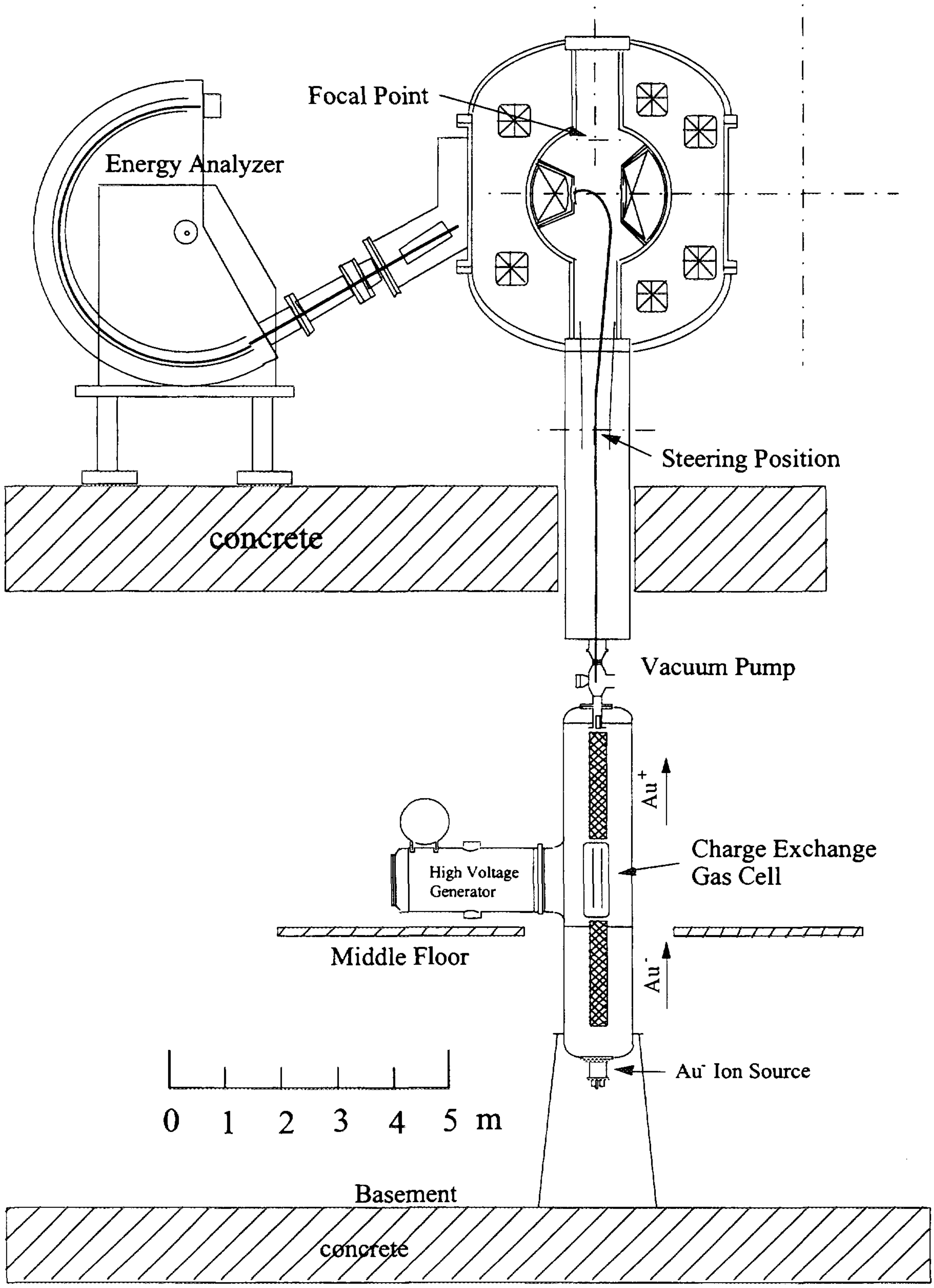

Fig. 2. A schematic drawing of the 6 MeV heavy ion beam probe.

provide a good opportunity for young scientists to be trained with a participation in the experiment. The establishment of a regional center for training young scientists and for encouraging the growth of innovative ideas will be of great help to promote the IAEA activities to bridge large scale institutions and small and medium scale laboratories for world-wide collaborations.

6. Conclusion

At NIFS, a construction of LHD device and preparatory works for LHD are in progress. Basic researches using smaller devices are also being carried out. The diagnostic developments for LHD are good example of combining the works in a wide range of fields and places.

The NIFS is ready for contributing international collaborations with an idea of regional center in Asian district.

References

[1] A. Iiyoshi, M. Fujiwara, O. Motojima, et al., Design study for the Large Helical Device, *Fusion Technology*, **17** (1990) 169-187.

[2] M. Fujiwara and the Large Helical Device Project Team, Status of large helical device project, *Fusion Engineering and Design*, **23** (1995) 547-561.

[3] A. Fujisawa, H. Iguchi, A. Taniike, M. Sasao and Y. Hamada, A 6 MeV heavy ion beam probe for the Large Helical Device, *IEEE Trans. on Plasma Science*, **22** (1994) 395-402.

[4] M. Sasao, Y. Okabe, A. Fujisawa, H. Yamaoka, M. Wada and J. Fujita, Development of negative heavy ion sources for plasma potential measurement, *Rev. Sci. Instrum.*, **63** (1992) 2726-2728.

[5] A. Fujisawa, H. Iguchi, Y. Hamada, M. Sasao and J. Fujita, Active control of beam trajectories for heavy ion beam probe on helical magnetic configurations, *Rev. Sci. Instrum.*, **63** (1992) 3694-3700.

[6] T. Taniike, M. Sasao, A. Fujisawa, H. Iguchi, Y. Hamada, J. Fujita, M. Wada and Y. Mori, Ion source and stripper gas cell developments for the 6 MeV tandem heavy ion beam probe on the Large Helical Device, *IEEE Trans. on Plasma Science*, **22** (1994) 430-434.