(5) Diagnostics Systems

For the precise measurement of plasma quantities in a three dimensional helical plasma, an extensive set of diagnostics have been developed with national and international collaborators, and are routinely operated in the LHD. The diagnostic system operating now consists of about 60 diagnostic instruments (Table I).

The YAG laser Thomson scattering (TS) system and the ECE system have proven as reliable diagnostics for the temporal evolution of the electron temperature profile. The YAG laser TS system works routinely to provide the electron temperature profile with a flexible repetition rate (from 5 ms to hundreds of ms). The LHD TS has an oblique backward scattering configuration, in which the typical scattering angle is 167 degrees. This unique configuration enables us to measure the electron temperature/density profiles from the boundary to the center of the LHD plasma. The system can measure the scattered light at 144 points along a major radius with the spatial resolution of 20 – 40 mm. In this scattering configuration, the TS spectrum width becomes wider than those in a conventional right angle scattering configuration. The measurable temperature range is 20 eV – 20 keV. In this fiscal year, the laser positioning system was developed to establish long term pointing stability of the laser beams.

For the electron density measurements of the LHD plasma, three kinds of diagnostics have been used: a multi-channel FIR laser interferometer, a two color mm wave interferometer, and a CO_2 laser imaging interferometer. A 13-chs FIR interferometer has been routinely operated for the precise measurements of the electron density profile. The optical configuration is of the Michelson interferometer type with a heterodyne detection system. The light source is a highly stable twin 118.8-μm CH_3OH laser pumped by a cw CO_2 laser. The spatial and time resolutions are 90 mm and 1 μs, respectively. For high density plasma diagnostic, a 10.6-μm CO_2 laser imaging interferometer has been developed. The imaging system is employed by using three slab-like beams (one 250 x 50 mm and two 280 x 50 mm beams) and multi-channel detector arrays (liquid nitrogen cooled photoconductive type HgCdTe detectors) to measure the fine structures of the density profile and fluctuations. The total channel number is 81 with a chord spacing of 7.5 – 15 mm. For subtraction of the phase shift due to mechanical vibrations, a 10 channels 1.06-μm YAG laser heterodyne imaging interferometer is used.

The reflectometer is a promising method for measuring electron density profile, and also has a higher spatial resolution than conventional diagnostic methods, especially in the edge plasma region. In LHD, there are three kinds of detection method for reflectometry, an ultra-short pulsed radar reflectometer, a frequency hopping reflectometer and a frequency fixed reflectometer. The most unique one is the ultra-short pulsed radar reflectometer. An ultrashort pulse has broad band frequency components in Fourier space. This means that one ultrashort pulse can take the place of a broadband microwave source. The time-of-flight (TOF) measurement technique is used for the delay time measurement of the reflected pulses from each cut-off layer in the plasma. For obtaining the desired frequency components, we utilize two impulse generators, -2.2 V/23 ps and -2 V/18 ps, and standard rectangular waveguides. And, for a multiple-channel and multiple-frequency band system with 28 channels in X-, Ka-, U-band frequency components, a new switching technique and multiplexer were developed.

The plasma potential profile, or radial electric field distribution, is an important quantity in a helical system, because it is closely related to the plasma confinement characteristics of helical plasmas. For the direct measurement of the electrostatic potential, a heavy ion beam probe (HIBP) has been developed in LHD. Due to the large size of the plasma confined in the magnetic field of up to 3 T, a MeV-range beam of heavy ions is needed. At the present, the error in potential measurement is estimated to be about 340 V, in which the main error sources are fluctuations of the acceleration and analyzer voltages, and electric noise of the amplifier. Er measured by the HIBP agrees with that estimated by charge exchange spectroscopy (CXS), which is another reliable diagnostic for determining Er by measuring the velocity of the plasma flow. We can measure Er across the entire radius of the plasma by using both HIBP and CXS

For multi-dimensional measurements of the non-axisymmetric LHD plasma 2-D or 3-D imaging diagnostics are under intensive development with national and international collaborators. A 3-D imaging system has been developed in collaboration with Kyushu University for the measurement of an electron temperature profile and its fluctuations and for the density fluctuation measurements. The 2D microwave imaging detector is a key device in this diagnostic. A 2D (4x4) imaging detector array was developed, which has a frequency bandwidth of 20 GHz. Each detector element consists of a Yagi-Uda antenna, a beam lead type GaAs Schottky barrier diode, two RF amplifiers and a SAW filter. The system was firstly applied to the reversed field pinch (FRP) plasma in TPE-RX for the measurement of density fluctuations.

Table I List of Diagnostics of the LHD

DIAGNOSTICS	PURPOSE	BRIFF DESCRIPTION
Magnetic probes	I_p, plasma pressure, magnetic fluctuations	Rogowski, Mirnov, saddle coils
MM-wave interferometer	$n_e l$	2 mm-/1 mm-wave, single channel
FIR laser interfeometer	$n_e l$ (r,t)	119-μm CH_3OH laser, 13 vertical chords channels with 90 mm spacing
CO_2 laser interferometer	$n_e l$ (r,t)	81 vertical chords, 7.5 - 15 mm spacing
Microwave reflectometer	n_e profiles and fluctuations	Ultra-short pulsed-rader, Frequency hopping, and heterodyne reflectometer
Thomson scattering	T_e(r,t), n_e(r,t)	200 spatial points, 20 - 100 ms time resolution
ECE Fourier spsctroscopy	T_e(r,t) with scan time of	f = 60 ~ 600GHz, Δf ~ 4 GHz, scan time of 25 ms
ECE Radiometer	T_e(r,t) and fluctuations	High time (~μs) and spatial resolutions
X-ray PulseHeight Analysis	T_e(r,t), impurities	Si(Li) and Ge detectors
Neutral Particle Analyzer	T_i(t) and energy spectra fE)	Energy range: 0.8 - 167 keV, 40 ch, Δt ~ 0.1 ms
CXS	T_i(r,t) and plasma rotation Vp(r)	Combination of heating NBI and visible spectrometer
MSE	Rotational transform angle	Combination of heating NBI and visible spectrometer and CCD detector
X-ray Crystal Spectroscopy	T_i (0) and plasma rotation Vp	ArXXI, TiXXI, CrXXIII, FeXXV, Δt = 20 ms
Bolometers	P_{rad}(r,t)	Resistive metal film, infrared imaging bolometers, Extreme ultraviolet photodiode
VUV Spectroscopy	Highly ionized impurity line	2 - 130 nm (Δλ = 0.01 nm), 0.4 - 4 nm (0.001 nm)
Impurity monitor	Monitoring impurity behaviors	Hα, HeI, CIII, CIV, OV, OVI, FeXVI, Δt = 0.1 ms
Zeff	Radial profile of Z_{eff}	500-600 nm, Δt = 0.1 ~ 100 ms, Δr ~ 2 cm
Soft X-ray and AXUV array	Impurity ions and MHD activities	20 chs photodiode array, Δt < 200 kHz
Soft X-ray Camera	MHD oscillations	2D image of soft x-ray radiation, Δt ~ 50 μs
Plasma monitor camera	Plasma position and shape	Real time video signal
CO_2 Laser PCI	Micro-turbulence	6 x 8 = 48 two dimensional detector Δr ~1/3 (k = 0.1 ~ 1 mm^{-1}), 1/10 (k = 3 mm^{-1})
Diagnostic Pellet (TESPEL)	Impurity transport	TESPEL (Tracer-Encapsulated Solid Pellet)
Heavy Ion Beam Probe	Plasma potential and fluctuation	Au+ (6 MeV, 10 μA), Spatial and time tesolutions: 1 cm and 1 μs
Langmuir Probe	SOL plasma parameters 3D structure of the helical divertor	Fast scanning (1m/s) in the SOL Probe array on the divertor plate
Li beam probe	edge density and its fluctuation	20 keV, 70 μA, FWHM ~ 20 mm
Visible/Infrared TV	Plasma-Wall interaction	TV systems
Divertor interferometer	$n_e l$ of divertor leg	Density resolutions of 2.3 x $10^{16} m^{-3}$, Δt = 10 ms
Lost ion probe	Escaping fast ions	Scintillator-based lost ion probe
Natural Diamond Detector	Charge exchange fast neutral	E = 0.03 ~ 3 MeV, ΔE ~ 9 % (FWHM)

A data acquisition system with parallel processing technology has been developed for diagnostics with a 3 minute cycle and a steady-state plasma sustainment during LHD operation. Data of most diagnostics are taken by CAMAC, WE7000, and CompactPCI digitizers. The total number of digitizer modules and channels are about 300 and 2000, respectively. In 11^{th} campagin in 2007, the maximum acquisition amount has increased up to 6.79 GB/shot, constantly having about 180 shots per day. For realizing non-stop real-time data acquisition in quasi-steady-state expetiments, the compactPCI standards can smoothly replace the CAMAC digitizer because of its popularity and low price due to the PCI compliance. As a result, the system has achieved its continuous data acquisition and transfer performance up to 160 MB/s, which contributes to the achievement of a new world record for the acquired data amount.

For effective remote participation by domestic universities and institutes, LHD has a powerfull network realizing 1 Gbps streaming by introducing the Super SINET. This system enables remote participants to see the same images and to access their diagnostic data from their institutes like the researchers in the controle room of LHD.

(Kawahata, K.)