Setup and Commissioning of New Diagnostics on the EAST Device

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1. Introduction

EAST (Experimental Advanced Superconducting Tokamak) device is aimed to achieve steady-state (SS) high-performance plasma sustained by intensive use of radio frequency heating and current drive, and to study fusion reactor-relevant physics and technology [1-6]. In the last 7^{th} experimental campaign in 2012, significant progress had been got. 400s long pulse plasma discharge (0.28MA, ne~1.2, Te~1.8keV, P_{LHCD}~1.2MW, Bt~2.5T), stationary H-modes with durations of 35 s (0.28MA, ne~2.2, P_{LHCD}~1.8MW, P_{RF}~1.2MW, Bt~1.9T, H98(y,2)~0.8) and 32s (0.4MA, LSN, P_{LH} ~1.2MW, P_{RF}~1.6MW, f=27MHz, Bt~1.9T), H-mode only by ICRH with a duration of 3.45s and effective ICRF heating (0.5MA, ne~2.0, Bt~1.9T, ΔW~30KJ) have been achieved [7-8]. To approach steady-state (SS) operation of high-performance plasmas and address key physics on fusion reactor-relevant subjects, tremendous and comprehensive upgrade of the EAST machine have been implemented exclusive of outer vacuum chamber after 7^{th} campaign. Capability of the auxiliary heating and current drive on the EAST are doubled with total injection power over 25MW, including new methodology of 4MW@NBI (Neutral Beam Injector), 6MW@4.6GHz LHCD (Low Hybrid Current Driving) and 2MW@140GHz ECRH (Electron Cyclotron Resonant Heating). New ITER-like upper mock-up divertor with W/Cu monoblock structure and enhanced active cooling, additional upper internal cryo-pump, new RMP (Resonant Magnetic Perturbation) and IC (internal coil) Coils for plasma shape and position control, wall conditioning technique (Li oven/granule drop/pellet) and fuelling method (GP, SMBI, Pellet), have been developed and employed.

Diagnostic requirements of the EAST are determined by demands of measurement and physics study to characterize the plasma behavior over the full range of conventional plasma parameters. Following the revolutionary upgrade of the EAST device this time, more horizontal ports are assigned to new systems for plasma heating and current driving, and many new advanced diagnostics especially neutral-beam related diagnostics must be developed and given the port space. Therefore, all diagnostics are rebuilt based on the principle of more compact integration due to limited port window and space available with emphasis on distinguished ability to provide all parameters' profile including the current density profile, global rotation and turbulence, and characteristics of the pedestal region in H-mode plasma, to study and understand critical issues specific to SS high performance plasma.

2. Setup of new EAST diagnostics

EAST diagnostic technique involves electromagnetism, spectroscopy, microwave, laser assistance, particle diagnostics and fusion products, etc. According to application and research objectives, it can be divided into four categories: plant operation and protection, plasma equilibrium and control, research of plasma behavior and performance, and physical understanding of plasma for acquisition of high-performance steady-state plasma.

1) Plant operation and protection

EAST diagnostic systems deploy necessary measurement and feedback signals required by plant operation and protection which are used to measure the basic physical parameters within the range of all EAST operation parameters. For instance, electron temperature and density in plasma core, plasma position and shape, plasma current and loop voltage, vacuum vessel current, HALO current, main impurities, effective charge number and radiation power of plasma, etc. Meanwhile, monitoring of all kinds of engineering and technical parameters which is required by the operation and protection of systems, equipments, components and personnel security, should be realized. The monitoring includes temperature rise and electromagnetic force of important components inside vacuum vessel (divertor plate, limiter, etc.), pressure in vacuum branch, cooling water flow rate and pressure, all kinds of valve operation and emergency protection, as well as real-time monitoring of ionizing radiation and dose rate inside and outside the machine hall, et al.

2) Plasma equilibrium and control

EAST diagnostic systems are asked to provide basic signals based on electromagnetic measurement, such as flux loop, magnetic probe and pick-up coil, in order to achieve plasma equilibrium reconstruction which are critical for active palsma feedback control on stability, soft ramp-up and landing, avoidance of hazards, various configuration formation for realization of different important scenarios. Combining the signals of density from far-infrared interferometer, MHD instability, visible video camera and radiation power, etc., optimization of the EAST plasma performance can be achieved through detailed study of plasma confinement, wave-plasma coupling, interaction between wave and plasma, and divertor plasma performance, particle exhaustion and heat removal.

3) Study of plasma behavior and performance

EAST diagnostic systems provide the spatial distribution of basic plasma parameters from the core to the boundary, including electron temperature and density, ion temperature and density, major impurities and their concentration, radiation power and energy spectrum, effective charge number, speed of runaway electrons and superthermal electrons, edge plasma structure, etc. Interaction between divertor and wall materials with plasma is monitored in order to provide the information of plasma up-down asymmetry, ablation of wall materials, and divertor plate and limiter temperature for possible erosion state, etc. The production and control of instability is studied to ensure plasma physics experiment on the rails. Currently, EAST diagnostic system upgraded comprehensively with the above capacity has been in commissioning to exhibit their function. It is expected that in one or two years, the usability and reliability of the diagnostic system, data validity and accuracy can be improved greatly. With the technique development of effective in-vessel calibration and collimation, rapid data processing methods, data fitting and interpretation together with model simulation, it will accommodate EAST requirements on various physics study.

4) Plasma physics understanding for acquisition of high-performance steady-state plasma

EAST diagnostic systems provide the spatial distribution of major plasma parameters from the core to the boundary, through projecting measurement data into magnetic surfaces using plasma magnetic surface reconstruction, acquiring plasma transport coefficient using a variety of programs and developing advanced and special diagnostic techniques especially closely related physical diagnostics which help to deepen the understanding of plasma stability, transport and energetic particles, to ensure active control of key parameters' profile. The ability of physical understanding of data is enhanced to furthest guarantee the needs of physical researches on high-performance and steady-state plasma, highly confined operation mode, advanced tokamak operation scenario, energy and particle transport, optimized divertor's ability to expel particles and heat load under near-reactor-core condition, and burn plasma study, etc.

3. Commissioning of EAST diagnostics

Integration of EAST diagnostics can been seen in Fig.1 in which downview of the diagnostics distribution, high integration with compact design and tight neighbouring interval between systems are illustrated. Too much energy has been spent during negotiation and design to accommodate more systems with reasonable viewing sights, interfaces both inside and outside, safety interval among outside subsystems. Even those, many issues are out of careful consideration. For example, movement and sealing of different shutters in periscope systems,

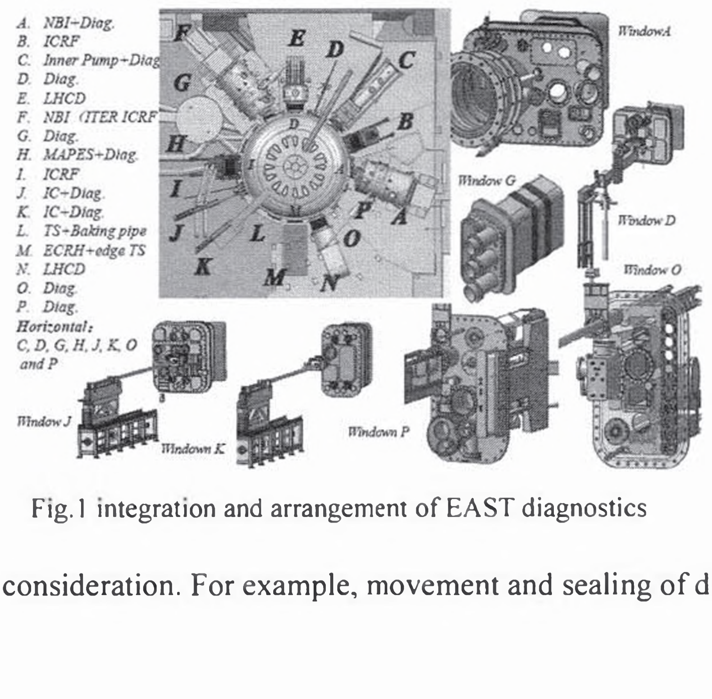

Fig.1 integration and arrangement of EAST diagnostics electrical shield in neighbourhood and grounding connection bring troubles occasionally. Therefore, further optimization before next campaign for those issues is necessary.

Totally there are eighty diagnostics constructed. Many of them are advanced diagnostics for physics study and understanding as listed in Table 1. They are expected to provide measurement for current density, plasma rotation, lost particles, density and temperature fluctuation, impurity, MHD instability, runway electrons, fusion product, et al so as to find control way for those parameters. The letters "P", "B" and "S" in Table 1 indicate diagnostic roles "Primary", "Basic" and "Supplementary", respectively.

Function	Plasma specification
Plasma rotation profile	Core: XCS (solid D), CXRS Edge: Hot-He beam (5mm, 50kHz, T>20eV, >1km/s); ERD(P&T), Edge-CXRS reciprocating probe
q profile/ j relaxation	P: 3 beam Polarimetry-Interferometry System (9ch. H); MSE (2014) B: SXR+EFIT reconstruction
Fusion product Neutron flux spectrum	3He + BF3, Fission chamber BC501 array (3ch)+
Lost ions	sFLIP, H-NPA, FIDA (active and passive, S&f,4cm)
Fluctuation (Te & Ne, V)	Core: CO2 laser scattering (CTS), ECEI (Te, 16chx26ch, 2.5-2.8T) Polarimetry-Interferometry (Ne), Poloidal and radial correlation reflectormeter Edge: Li-BES (Ne/r2cm,p1cm); DBS reflectormeter(Ne/V_θ); GPI (Ne, 2mm,400k); Hot He –beam (100K); Fast CCD; MW reflectormeter; ME-SXR (Te, slow); Reciprocating probe+HFS probe
MHD instability Lock mode (MHD)	ECEI (16chx16ch, 2.5-2.8T), 2D T-SXR camera, Mirnov coil SXR camera, Tang. SXR, Saddle coil
Runaway behaviors	Midplane: BGO + NaI (Forward+backward), IR camera NaI array (5ch) + CdTe + BGO array (4ch)
Edge plasma parameters RF sheath behavior	Reciprocating probe, Bolometer, Tri-probe, Mach probe, Ha/Da, GPI Katusmata probe, Microwave reflectormetre

Table1 Diagnostics for plasma physics understanding

Some of new diagnostics address to burning plasma study. During development of advanced diagnostics, comprehensive international collaborations have been carried out in different way. Young scientists and talent are educated and become source that plays continuous role in diagnostic technical development and relative physics research. Mutual collaboration will help EAST data configuration construction in wide international frame for sharing and analysis. It is believed that rebuilt EAST diagnostics and efforts involved will enhance EAST device in coming years to find ways for extension of operation regimes with high performance SS plasma in scenarios of longer H-mode, ITB, high β etc., and to seek for answers of new physics and existing observations which have not be fully understood.

With the dramatic increase of the EAST heating power and coming unignored radioactivation and radiocontamination, for the first time, distribution of the ionizing radiation and dose rate of the EAST, mainly on local radiation of neutron and gamma, are measured intensively and formally as shown in Fig.2 to give reasonable estimation of environmental radioactivity to give safe protection for

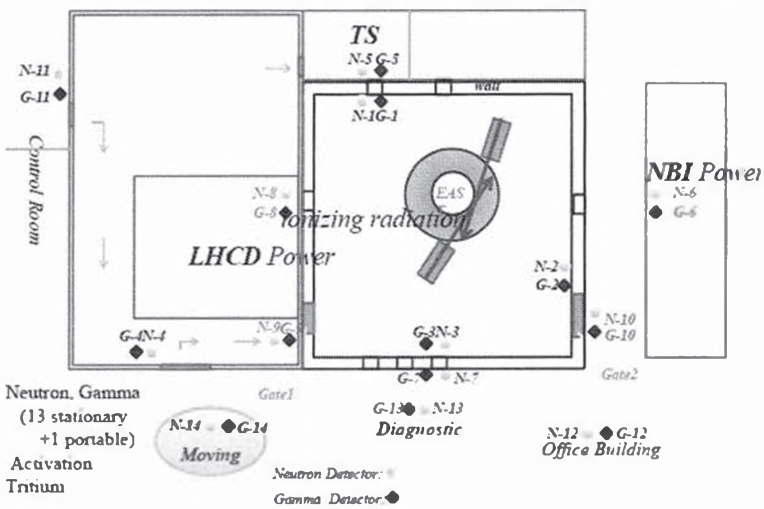

Fig.2 Measurement distribution of ionizing radiation and dose rate

local workers and environment.

4. Summary

Rebuilt EAST diagnostics with more advanced and specific diagnostics will provide more usable and valid data to allow good start for deep physics study and understanding. Data structure construction, data processing and effective interpretation combing with integrated modelling are needed with big efforts to push diagnostics work more reliably and effectively to accommodate EAST requirements on various physics study.

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