Diagnostics development on the EAST superconducting tokamak

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Introduction: EAST (Experimental Advanced Superconducting Tokamak) device is aimed to achieve steady-state high-performance plasma sustained by intensive use of radio frequency heating and current drive, and to study relevant physics and technology. The initial three campaigns were addressed the feasibility of the full superconducting magnets and control algorithm with new features to explore some critical issues relating to steady-state operation with shaped plasma configurations. Since the third campaign in 2008, many new techniques have been employed to upgrade DN divertor plasma performance, including modification of in-vessel structures and PFCs, iso-flux real-time feedback control, full graphite wall with active water cooling, internal cryo-pump, etc., much significant progress has been achieved [1-2]. Repeatable long divertor plasma discharges with 0.25MA/1minute, 0.25MA/8s fully non-inductive current driven by 1MW LHW had been demonstrated in the 4th campaign last year. In recent 5th campaign, 0.83MA/8s plasma sustained by 1.3MW LHW, and 0.4MA plasma with 2.5MW injected RF power (0.8MW LHW plus 1.7MW ICRF) are obtained. In the meantime, ICRF wave coupling with plasma, LHCD current drive and heating, divertor plasma behavior, plasma initiation with LHW assistant and different wall conditioning techniques have been carried out and studied.

Setup of diagnostics: 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, which are varied in different operation scenarios. Basic diagnostics, as illustrated in Fig.1, consist of plasma position and shape, plasma current and loop voltage, vacuum vessel current, electron density, electron temperature, impurity species, various of plasma radiations in different energy range, temperature of the limiter surface and divertor plates, vacuum pressure and mass spectrum, mainly for monitoring and control of machine operation and protection. In the initial two EAST campaigns with full stainless-steel first wall and hydrogen operation gas, except in-vessel diagnostics like magnetic diagnostics, divertor probe and thermocouple, external diagnostics were those used on HT-7 tokamak with some modification of connecting flange and cables due to short of budget. Since the 3rd campaign in 2008, diagnostics have been set up gradually to accommodate EAST features of DN/SN configuration and cover whole region of conventional plasma operation, tens of diagnostics have been employed until the 5th campaign 2010. Some key diagnostics for profile of parameters, such as a Nd:YAG Thomson scattering system [3] and a x-ray imaging crystal spectrometer (XCS) [4] etc., shown in Fig.2 and 3, are applied recently for evaluation and optimization of the plasma performance, and further for plasma physics understanding.

Basic diagnostics: magnetic diagnostics involved in plasma equilibrium reconstruction and real-time feedback control were constructed with enough spatial resolution and high accuracy better than 1% for measurement of plasma current and PF coil current with Rogowski coils, and better than 3% for measurement of the poloidal field with magnetic probes and poloidal magnetic flux with flux loops. Combined with a plasma control system (PCS) built in tight collaboration with GA/USA, which is similar to the PCS of DIII-D, real-time EFIT (RTEFIT) for the plasma equilibrium reconstruction and ISOFLUX for the position control of special 8-point on last close magnetic flux surface was realized successfully to obtain DN plasma with elongation κ=1.9/triangurity δ=0.40, SN plasma with κ=1.7/δ=0.64, and to control LHW driven plasma for 63s with ISOFLUX feedback control more than 60s, which already covering all EAST designed configurations. Two groups of Mirnov probes in toroidal direction, each with 38 two-components in poloidal direction with accuracy of 10%, 100 kHz, together with soft x-ray photodiode (PDA) cameras for tomographic reconstruction are used to identify and study MHD instability. Plasma store energy is measured by three groups of diamagnetic loop in toroidal direction with an accuracy of 15-20%.

Two tangential visible CCD cameras and one tangential IR CCD camera provide images to support machine operation and protection. A vertical 3ch. far-infrared (FIR) 337-μm HCN laser interferometer for line average electron density and gas puffing feedback control, the 25ch. multipoint & multipulse Nd:YAG Thomson scattering system for electron temperature and density, a horizontal 15ch. soft x-ray PHA and a horizontal 16ch. ECE for electron temperature, together with two sets of soft x-ray PDA orthogonal cameras (3, each with 35ch.) and a set of AXUV PDA camera (2, each with 16ch.), 8 ch. visible bremsstrahlung measurement for effective charge number, have been employed to study core plasma behavior. Divertor and edge plasma is studied with three 35ch. PDA Hα/Dα cameras, two viewing upper and lower divertor region horizontally through a reflecting mirror and one viewing lower dome region from the top, joined with fixed divertor Langmuir probes near the divertor target plate and two fast reciprocating probes (2m/s). Combing with fixed Mach probes, fluctuations of potential and density in the plasma boundary like the blob, zonal flow, GAM etc., can be investigated as well. The spatial impurity line radiation is provided by two OSMA (Optical Spectroscopy Multi-Channel Analysis in a spectrum range of 200~700nm, one with fine resolution 5nm, the other with 70nm), two UV-VIS monochrometer mainly for CIII, OII and LiI, one fibre optical spectrometer (200-700nm), and a vertical 18ch. CIII PDA array, while heavy metal concentration can be also monitored by the horizontal 15ch. SXS PHA system. Profiles of radiation flux and energy of the energetic electron is measured by a tangential hard x-ray array with CdTe detector, especially for wave deposition during LHW injection. Runaway behaviors with radiation flux and energy are monitored by a vertical array of NaI(TL) scintillator (1.0-10MeV), a set of tangential system with BGO scintillator (0.5-7MeV) and CdTe (0.3-1.2MeV). Neutron yield measurement is also available using an external 235U fission chamber and four channels of ^{3}He proportion counts detectors for neutron flux, while the spectrum of the neutron is provided by a liquid BC501 monitor.

Diagnostics for key parameters' profile: The high-resolution poloidal and tangential XCSs are implemented on EAST to provide spectrally and spatially resolved images of the plasma on the ion and electron temperature, poloidal and toroidal impurity rotation velocity for all experimental conditions, which are derived from satellite spectra of helium-like argon Ar XVII. Ti, Te and electron density are obtained, the clear toroidal flow with a maximum value of 40 km/s is observed by the XCS for LHCD plasma, and the direction of toroidal flow in core region is consistent with that in edge region measure with the Longmuir probe. More details will be presented in the coming IAEA meeting. The upgraded 2D ECE image system with non-spherical (hyperboloid) lens and dual dipole antenna mixers is used to collect the 2nd harmonic of ECE from the core plasma, working well in the frequency ranges of 100~120GHz with the magnetic field 1.4T~2.5T to study core MHD activity and real time fluctuations of the electron temperature. A Pt resistor bolometer array with capability of 14 miniaturized 4ch.-units (IPT-Albrecht GmbH) is setup to measure radiated power and study global and local energy balance. Other systems like 20-channel grating polychromator (GPC), gas puff imaging (GPI), and 32ch. ECE system are in preparing for coming EAST campaign.

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References: [1]Baonian Wan, 3rd EAST IAC meeting, Hefei, China, May 14-15, 2009

[2]Baonian Wan, etc., 22nd IAEA Fusion Energy Conference, OV3-4, October 13-18, 2008, Switzerland

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[4]Y.J. Shi, etc., 5th PRC-US Magnetic Fusion Collaboration Workshop, May 5-7, Wuhan, P. R. China

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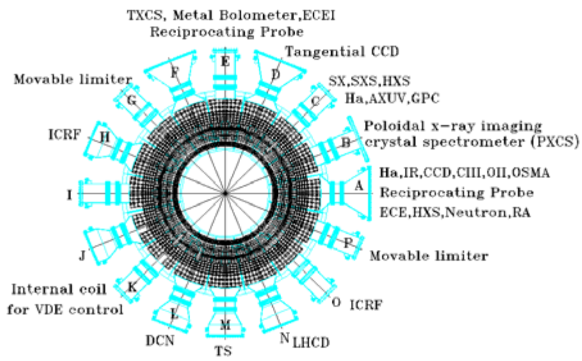

Fig.1 Down view of the EAST diagnostics arrangement

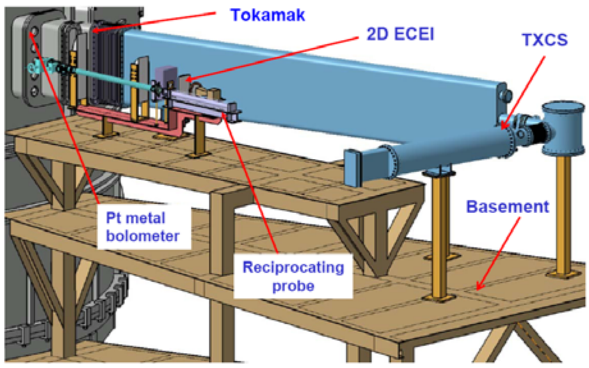

Fig.2 key diagnostics on the integrated window E

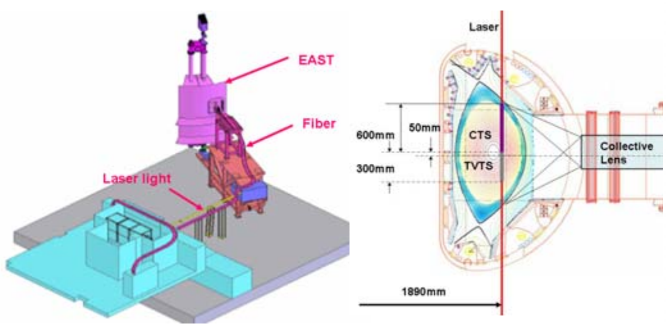

Fig.3 25ch. Nd:YAG Thomson scattering system

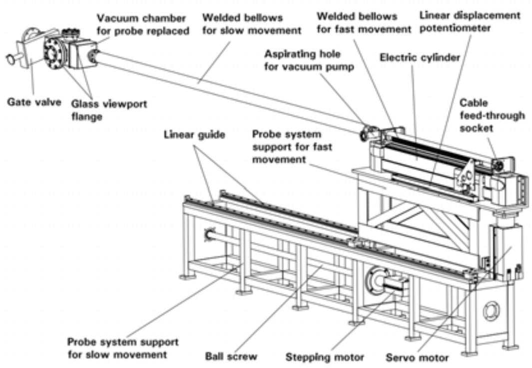

Fig.4 A fast reciprocating probe