EAST Next Five-year Plan

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1. Introduction:

Experimental Advanced Superconducting Tokamak (EAST) as shown in figure 1 is the first fully superconducting tokamak which was approved by Chinese government in July 1998. Its mission is to conduct fundamental physics and engineering researches of advanced tokamak fusion reactors with a steady, safe and high performance, to provide a scientific base for experimental reactor design and construction. EAST construction started in October, 2000. The assembly was finished at the end of 2005 and the commissioning was completed in March 2006[1]. Progress has been made in plasma operation during past few years [2-3]. During the next 10 years for ITER construction, together with LHD, KSTAR, JT-60SA and WEST tokamaks, EAST will be an important experimental test bench for conducting ITER related steady-state advanced plasma science and technology research.

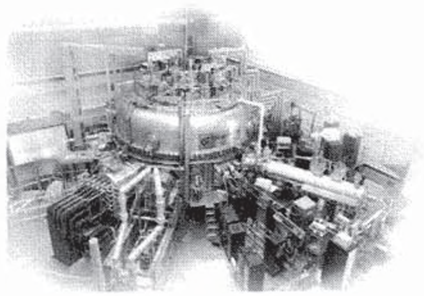

Fig.1 Experimental Advanced Superconducting Tokamak (EAST)

2. Present State of EAST

Since 2010, significant progress has been made on EAST on both physics and technology fronts towards the long-pulse operation of high-confinement plasma regimes. Over 400s divertor L-mode plasma discharges and long pulse H-modes with duration over several tens of the current diffusion time have been achieved on EAST by the combination of lower hybrid current drive (LHCD) and RF heating. Remarkable efforts have also been made in mitigating type-I ELMs in stationary state H-mode plasma with multi-pulses of supersonic molecular beam injection (SMBI), LHCD, lithium granule and deuterium pellet injection. Over 30s long-pulse H-mode discharges with $H_{(98,y2)}\sim 1$ have been obtained either with ELM mitigation or in a small ELMy regime accompanied by a new electrostatic edge coherent mode. The peak heat load on the divertor, which is over 10 MW/m^2 during type I ELMs, is reduced down to 2 MW/m^2 either by SMBI or LHCD [4-5].

Tremendous efforts have been made during past two years to enhance the EAST capabilities; nearly every sub-system except superconducting magnets has been upgraded or modified to enable higher performance and truly steady state operation. The major upgrades include:

- H&CD systems have been upgraded around 30MW, namely 4 MW CW 2.45GHz and 6MW 4.6GHz LHCD systems, 12MW CW ICRF system with wide band frequency of 25-70MHz, 4MW 50-80keV NBI system. The 2^{nd}4MW NBI and 2MW ECRH of 140GHz could be ready in October.
- 78 different diagnostics are installed, and all key profiles of plasma parameters will be provided during the coming experiments.
- Upper divertor has been changed into ITER-like W monoblock configuration with up to $10MW/m^2$ heat removing capacity as shown in Fig. 2.
- Top and bottom internal crypumps have been installed with a $160M^3/s$ pumping speed together with enhancement of external pumps.
- 16 ITER-like RMPs coils together with several other new ELM mitigation methods, such as supersonic beam injection, CW Li&D_2 pellet injectors, gas puffing from different target places, up to 1kHz power modulation of H&CD systems(LHCD, ICRF, NBI,ECRH), have been implemented.
- Two pairs of ITER-like VS coils have been installed to better control plasma vertical displacements. Fast control power supply and plasma control system have been upgraded to facilitate the control of high plasma performance discharges.
- Other systems, such as PF&TF power suppliers, cryogenic system, cryogenic transmission line, HTc superconducting current leads and fueling systems have also been upgraded towards more reliable operation condition.

2014 EAST second experiment campaign is planned to start from late October when the second NBI and ECRH are ready, and last till the end of January 2015. Challenges on plasma control, effective H&CD, plasma-wall interactions under long pulse, high heat flux (over 10MW/m2) and high-Z metal wall conditions will be tremendous.

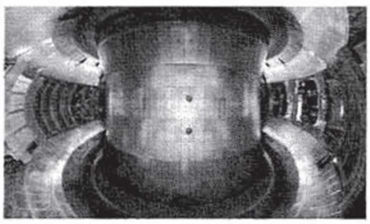

Fig.2 EAST internal plasma phase component structure

3. Next Five Year Plan

Next five year is a very important period of time to explore most of key issues for ITER under steady-state operation condition on EAST. Major efforts will focus on capacity improvement and high performance plasma discharges.

Further increase of H&CD power and diagnostics under CW condition will be one of most important efforts. Since LHCD&ICRF are in very good condition, the establishment of 10MW CW ECRH and optimization of long pulse NBI system will be the most challenging tasks. Fig.3 shows the future arrangements of major hardwares on EAST during next 5 years.

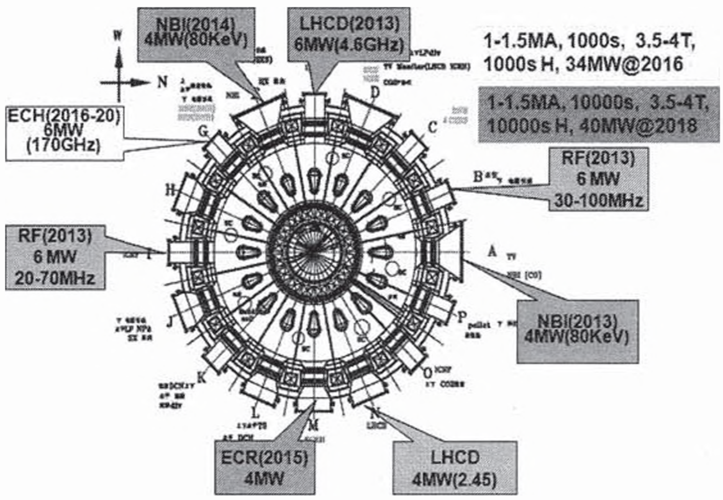

Fig.3 Arrangements of EAST major hardwares for next 5 years

With over 30 MW long pulse H&CD and 80 different advanced diagnostics, EAST will have unique capabilities to address many of the critical physics and technology issues that ITER will encounter. EAST is capable of pulse durations beyond 400 seconds (similar to ITER) with high power electron heating (as in ITER) to challenge power and particle handling at high normalized levels (10MW/m^{-2}) comparable to ITER. EAST also aims to explore steady state operation with advanced tokamak characteristics which would be of great value to ITER but also could lead to an attractive fusion power plant. The table 1 shows the expected plasma performance up to 2018 before ITER construction.

Table 1 Plasma parameters during next 5 years

Parameters \ Year		2014	2015	2016	2017	2018
Ip(MA)		1.0	1.0	1.0	1.5	1.5
LHCD (MW, CW)	2.45GHz	4.0	4.0	4.0	4.0	4.0
	4.6GHz	6.0	6.0	6.0	6.0	6.0
ICRF(MW,CW) 25-70MHz		12	12	12	12	12
NBI(80keV)		8.0	8.0	8.0	8.0	8.0
ECRH		1.0	2.0	4.0	6.0	10
Diagnostics		70	80	80	80	80
Duration(s)		400	1000	1000	1000	1000
t-Hmode(s)		100	400	400	1000	1000
Beta N		2	2-3	2-3	2-3.5	2-3.5

The overall focus of the EAST program in the next 5 years is to develop the scientific and technical basis for high-performance, steady-state operation in ITER and future tokamak reactors. The EAST team has established as a long-term target of very long pulse (400 s) plasma operation with a plasma current $I_P = 1$ MA, normalized beta $\beta_N \geq 3$, bootstrap fraction $f_{BS} > 0.5$, and line-averaged density > 0.6 times of the Greenwald limit. With the power available from 2014, steady state scenarios at $I_P = 0.5$ MA scenario are within reach and will start soon, which will be an exciting and important step toward EAST's long term goals.

To achieve these overall goals requires advances in both technical performance and physics understanding in several areas. Efforts will be made on the following key issues:

•High-power heating and current drive at high density. The EAST facility will start operation in 2014 with 22 MW of RF H&CD source power. Physics issues associated with high-power heating, such as coupling and power deposition at high density, control of power levels and wave phasing, and energetic particle effects, will also need to be further explored.

•Power and particle exhaust in steady-state (400 s) and high power density (~10MW/m^2). Heat and particle removal, compatible with high plasma performance, is essential for successfully making use of EAST's high-power heating capabilities. The EAST team has already made a strong effort in edge physics, and this emphasis will continue as the program moves toward higher power input and longer pulses. On the technical side, operation with new equipment (e.g., ITER like tungsten divertor, internal cry pump) and higher heat loads will increase risks associated with, e.g., component over-heating, deleterious plasma-launcher interactions, and coolant leaks. Attention will be given to mitigating these risks. On physics side, impurity radiation feedback control in both core and DSOL will be continue, together with newly developed snowflake configuration towards long pulse operation.

•Plasma measurements. The EAST facility has, and is still expanding an extensive set of diagnostics making plasma measurements needed for equipment protection and for control, characterization, and understanding of high-performance steady-state plasmas. Future efforts will focus on attaining a high level of availability and reliability in these diagnostics so that they can successfully fulfill these roles. The transition to operation with several-minutes-long pulses will require an evolution toward more efficient steady-state data acquisition strategies, e.g. event-triggering or real-time data reduction.

•Theory-experiment coupling. The theory team has developed simulation capabilities that start to be used to identify steady-state operating scenarios. Going forward, strong theory-experiment collaboration will be essential for the EAST experiment to use these capabilities to maximum advantage in designing and interpreting experiments. More data including detailed plasma measurements will be needed to make comparisons between simulation and experiments. The efforts will focus on subjecting codes to experimental validation as well as understanding the experiment.

•Plasma control. The EAST facility is equipped with an impressive array of plasma control tools, including new three-dimensional control coils, and benefits strongly from international collaboration in the plasma control area. Steady state tokamak operation will require excellent plasma control, including, e.g. control of edge-localized modes (ELMs) and other instabilities, avoidance and mitigation of disruptions, density control, and pressure and current profile control at high density. Using its available tools, and guided by physics measurements and simulations, the EAST control team will work to establish and over time, systematically expand, the operating space for steady-state plasmas.

•ELM mitigation and control. The giant Type-I ELM is unfavorable and must be mitigated in ITER operation due to very strong interaction with plasma facing material which could be easily damaged during long pulse ELM plasma discharge. A few ways for ELM mitigation have been successfully tested on EAST, such as D_2& Li pellets, supersonic beam injection, and modulated LH wave. 16 ITER like RMP coils have been installed on EAST which could provide different RMP fields of m/n numbers to mitigate ELM. Newly installed ICRF, NBI and ECRH can be operated in a power modulation level up 1 kHz frequency. By using the newly developed methods, together with previous ELM mitigation methods, EAST will establish a few simple and robust ELM mitigation methods towards the application in ITER and future reactor.

4. Summary

The new developed capabilities (over 30 MW long pulse H&CD, actively cooled ITER-like W divertor, 80 diagnostics) will advance EAST to the fore-front of international magnetic fusion facilities which makes it possible in the next five years to be capable of long pulse (400s) high performance discharges. Meanwhile the challenges facing the EAST team in bringing all these new systems into routine operation will also be huge and the risks are high. EAST team together with its international cooperators looks forward to embracing these challenges and significant scientific output which will benefit ITER and the wide international fusion science and technology community.

Acknowledgements:

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