Overview Progress and Future Plan of EAST project

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Abstract

EAST is a full superconducting tokamak with advanced configuration. The physic and engineering design; the R&D for the fabrication and testing of CICC and all magnets, for the key components such as insulators, high Tc current leads, as well as the most of important sub-systems such as the 2kw cryogenic system, the PF and TF power supply, the control and data acquisition system have been completed since 1998. The final assembly has completed at end of 2005. Basing on above progress the first engineering commissioning of EAST has been done successfully. The all magnets were cooling down to 4.5-5 K stably and then charged successfully. 8200A (2.0T) with the 5000 S charge duration for TF system has been achieved. The all subsystems has been also tested and showed satisfying the design requirements. The first plasma discharges have been obtained. The future experimental plan, especially for diverter experiments with long pulse discharge will begin soon. All of progress above and future plans of EAST project will be given in this paper with the individual reference papers in detail.

1. Introduction:

EAST is an Experimental Advanced Superconducting Tokamak which was approved as the National Mega-Projects of Science Research (MPSR) by Chinese government in 1997.

The mission of EAST project is to be widely investigation both of the physics and technology for steady state advanced tokamak as well as the investigation of the power and particle handle under the steady-state operation condition. The basic requirements for EAST tokamak are: both TF and PF, differing from existing superconducting tokamak, are superconducting magnets; enough inductive current system for plasma start up and heating; CW non-inductive current drive and CW addition heating systems for steady state operation; the large operation space, the flexible J(r) and P(r) control, the reliable and quick plasma position and shaping control for advanced tokamak flexibility; the standard PFC with changeable tiles for advanced first wall martial development; the divertor for power and particle handle and advanced diagnostics.

2. Composing and characteristics of EAST

2.1 The main parameters of EAST [1] are B_t=3.5 T, R_0= 1.75 m, I_p= 1MA, a= 0.4m, (b/a)= 1~2 with the flexibility of double and single null divertor configuration. At the first phase P_{LHCD}= 3.5 ~ 4 MW, P_{ICRH}= 3 ~ 4 MW, P_{ECRH}= 0.5MW and the maximum pulse long will be 1000 second (see table 1). If the temperature on the magnets can decrease from 4.2 K to 3.8 K the second phase with B_t = 4.0 T and I_p = 1.5MA will be achieved and the power for addition heating and current drive will be increased further (table 1).

2.2 EAST consist of following sub-systems (Fig 1):

- EAST tokamak, including sixteen D-shaped TF SC magnets, twelve PF SC magnets, the VV and in-vessel components, thermal shields (TS) and cryostat vessel (CV) and machine diagnostics.
- Pumping and fueling systems

- Cryogenic and refrigerator system (2 kW/4.5K, 13kW/80K) and 13 pairs of current leads.
- Power supply systems, including the TF power supply system (TFPSS), the 12 sets of PF power system (PFPSS), the fast control power supply system (FCPSS), the power supply systems for plasma current drive and heating.
- Plasma control and data acquisition systems
- Current drive (LHCD) and plasma heating (ICRH) systems.
- Plasma diagnostics
- 110 kV transmission line and 81.5 MW transformer substation
- Water cooling system
- The cryogenic test facility system for all SC magnet test.

2.3 There are following characteristics for EAST tokamak

- Both TF and PF are superconducting magnet with the 'D' shape configuration
- All magnets were wound with special designed CICC (see table 2);
- Double layer and 'D' shape VV with the ability to bake and cool the VV or shield the neutrons in the case of D-D discharges with high performance;
- Each of PF magnet has the own individual power supply, which gives the ability to get many kind of configurations from double null to single null;
- 5 pairs of current leads, especially the TF current leads, are high T_c, which significant decreases the 4.5 K heat load;
- Almost all of key componets, such as 35 Km of CICC, several hundred insulators, all TF and PF coils, 2KW cryogenic system, 69 MW PF power supply, high T_c current leads were designed, fabricated and assembled by our team in ASIPP.
- To insure the safety and quality of EAST tokamak all of SC magnets were cooling down and charged to the design level or above before the final assembly;

3.Overview progress:

3.1 Milestone of EAST project

- The project was approved by central government at 1977 with the limited total budget;
- 1998 –2000, evaluations, conceptual and preliminary design;
- 2000-2005, the engineering design some R&D, fabrication, components testing and first general assembly were completed;
- Feb. to March of 2006, the first engineering commissioning was full success;
- The 3.5 T for TF and 13 VS flux change for PF system were achieved at September 22 and the EAST project successfully passed the national evaluation of construction phase;
- The first plasma obtained on EAST at September 26 and the first experimental campaign begun since that time and the significant progress for plasma discharges have been achieved under very close collaboration with GA and PPPL;

3.2 Main results of the important progress [1-15]:

3.2.1 The key components such as CICC, TF and PF magnets were successfully produced and fabricated with good quality within three years in ASIPP;

3.2.2 All of TF and most of PF coils and few model coils were tested (cooling done and charged) successfully before the final assembly. The test results show the performance of all magnets satisfies the requirements of design. Fig 2 shows the test result of the first central solenoid coil.

3.2.3 the results of the first engineering commissioning:

The first commissioning was started on Feb. 1, 2006 and finished on March 30. The main purpose of the commissioning consists in testing the EAST device and its subsystem's engineering performance and capabilities, exploring the reliable scenarios for plasma operation, acquiring the key technical parameters of both the device itself and its sub-systems as well as validating the reliability of the interlock, safety and protection system. Total 260 shots have been energized. The longest TF current duration was 5000 seconds and the highest TF current was 8200 A, corresponding to an intensity of the toroidal field of 2 T. All the testing results showed that the EAST device and its sub-systems are successfully built. The results are:

- Pumping system started on Feb. 7 and was successfully operated through whole commissioning period. The lowest vacuum in cryostat reached 3.8×10^{-5} Pa that was below the operating requirement of 2×10^{-4} Pa.
- The 2 kw/4.5K cryogenic system was put into operation on Feb. 10 and the devices cooling down started on Feb. 18. All of the coils (215 ton cold mass totally) were cooled down to 4.5 K on March 4. The test record is shown in Fig. 3. The cryogenic system was optimized and reached to its designed state. The mass flow rate in each cooling channel was above the design value. The power of refrigerator reached 2.4 kW/4.5 K.
- 4 sets of PF power supply systems and TF power supply system were connected to different coils and have been tested successfully. The results showed that the systems are reliable.
- Main control system, data acquisition system, plasma control system (with the help of GA colleagues, USA), the interlock and safety protection system were tested. The systems met the requirement of commissioning operation.
- The magnet instrumentation was tested. The results of both the temperature and coil resistance measurements showed to be reasonable. The 87 joint resistances were below 10 nΩ, which meet the design and operation requirements.
- All the coils were energized with different currents and ramping rates. Individual coil, including two different PF coils, 4 PF coils, 4 PF with TF coils have been tested. The longest TF duration of 5000 seconds is shown in Fig. 4 with a highest TF current of 8200 A, corresponding to an intensity of the toroidal field of 2 T, and the highest PF current ramping rate was 20 kA/s. A total 260 shots have been operated for quench testing, joint resistance and magnetic configuration measurements.
- Quench detection and magnetic diagnostic obtained large amount of data which were very useful in getting reliable quench protection and magnetic configuration for setting a reliable data base for internal components installation in near future.
- 18 copper current leads and 8 High Temperature Superconducting (HTS) current leads worked properly and passed the testing.
- A few problems were found, indicating the further efforts should be made for the completion of the construction of EAST: One minor leakage has been found during

cooling down with 0.6 Mpa pressure in the cryostat thermal shield cooling circuit, which is acceptable for the future operation. It has been fixed in April; The isolation level dropped from the design value of 5 kV to 1 kV after connecting the instrumentation wires to the cryostat feed-through and connecting the superconducting bus bar to the current leads. Efforts should be made for getting the isolation level at above 5 kV and it also has been solved in July; One turbine in cryogenic system was damaged which caused serious delay for the schedule to obtain the first plasma, but in summary the first engineering commissioning of EAST tokamak was done very successfully.

3.2.4 After the first commissioning, the port extensions were welded with the vacuum vessel together, completed the full machine construction. The full stainless steel in-vessel components including liners, diverter plates, internal coils, RF antenna, etc were installed. The final assembly with the in-vessel components such as movable limiters antennas of both LHCR and ICRH, many diagnostics, baking system and divertor configuration protect plate and fast control coil system has been completed, which only take for four months (see Fig. 5).

3.2.5 The superconducting magnets were begun to cool down in July 2006 for the first experimental campaign. All the magnets were cooled to 4.5 K and tested up to their full designed performance with corresponding power supplies. The toroidal magnet was excited to 14.55 kA (designed at 14.3 kA) corresponding to 3.55 T at R = 1.7 m and 13 VS flux changes have been achieved by PF system. All systems needed for the first plasma passed the testing and checking by an expert group nominated by Chinese Academy of Sciences in 21-22 September 2006.

3.2.6 the first plasma discharges have been achieved successfully at September 26.

After the first engineering commissioning was a great success in March 2006, the first plasma with plasma current up to 220 kA has been successfully achieved in September 26 2006 on EAST with the collaboration of General atomic and Princeton Plasma Physics Laboratory, USA. The success of the first plasma discharges announces that EAST construction is completely successful. EAST is the first full superconducting tokamak at mega-ampere scale in operation. It will be in a unique facility to explore relevant issues relating to continuous operation with the shaped plasma cross-section in few years.

For the first plasma discharges, the machine was equipped with 5 new built diagnostics and other 10 diagnostics moved from HT-7.The plasma discharge was controlled by a plasma control system (PCS) built under the collaboration between General Atomic (GA) and ASIPP, which is similar to the DIII-D PCS, but with new EAST features. The RF systems at ICRF, 30 kW and at LHW frequency, 180 kW were available for purpose of wall conditioning and pre-ionization of discharges. Two movable molybdenum limiters were installed at R= 2.38 m, which allow maximum plasma minor radius up to 0.45 mm with the major radius of 1.95 m in circular cross-section.

The first DC glow discharge and RF plasmas (Fig.6) were obtained in August 2006 for wall cleaning with baking together. The first ohmic plasma was achieved in September 26, the day-one plasma discharges. To achieve reliable break down and plasma current ramping up, the machine was boronized by RF discharge, which was used as routine wall conditioning in HT-7. Considering limitations of PF current ramping rate, plasma initiation was carefully simulated by taking into account eddy currents in the vacuum vessel and models of the power supplies. At B_T=2 T @ 1.7 m, the break down. was successfully achieved (Fig.7 EAST shot 1138).

After 6 repeatable breakdown shots, plasma current was very smoothly ramped up to 150 kA with rate of about 0.5MA/s by pre-programmed control (Fig.7 EAST shot 1144) and up to 220 kA after further 7 shots. The plasma current of 220 kA and duration of 2.2s has been achieved up to now. Now the plasma discharges are still going on with the feedback control of the density and plasma current and position. We will try the plasma shaping experiments in few days.

4. Experiment plan for near and future [16]**:**

1) Commissioning discharges with the circle cross-section at the beginning operation phase;
2) Experiments on shaping and control the advanced configuration with PCS and individual PF power supply under the CW CD and addition heating condition;
3) Double and single null divertor experiments with different modes under long pulse or steady state operation condition;
4) Go to second operation phase: decreasing the temperature on SC magnets from 4.5K to ~ 3.8 K; increasing I_P from 1 MA to 1.5 MA; increasing LHCD and ICRH power and NBI totally from ~7 MW to ~15 MW for higher performance, especially higher β value under long pulse or steady state condition with different advanced configuration.

Summary

1) EAST has been successfully constructed within about 5 years with limited budget;
2) EAST was passed the engineering commissioning successfully.The rate B_T=3.55 T , $\triangle\Phi\geq$10 VS and dI/dt ～10-20 kA/ S have been achieved, which means the engineering design, fabrication and assembly are satisfactory.
3) The first plasma discharges have been successfully achieved and more experimental results will be provided in post deadline paper.

The all above progress and success indicates: EAST has been successfully constructed and is ready for operation when it will provide fusion community a very good international research facility for steady state divertor plasma research. The progress and future experiments of EAST will certainly benefit both to the construction, operation of ITER and the consideration of next national fusion research project in China.

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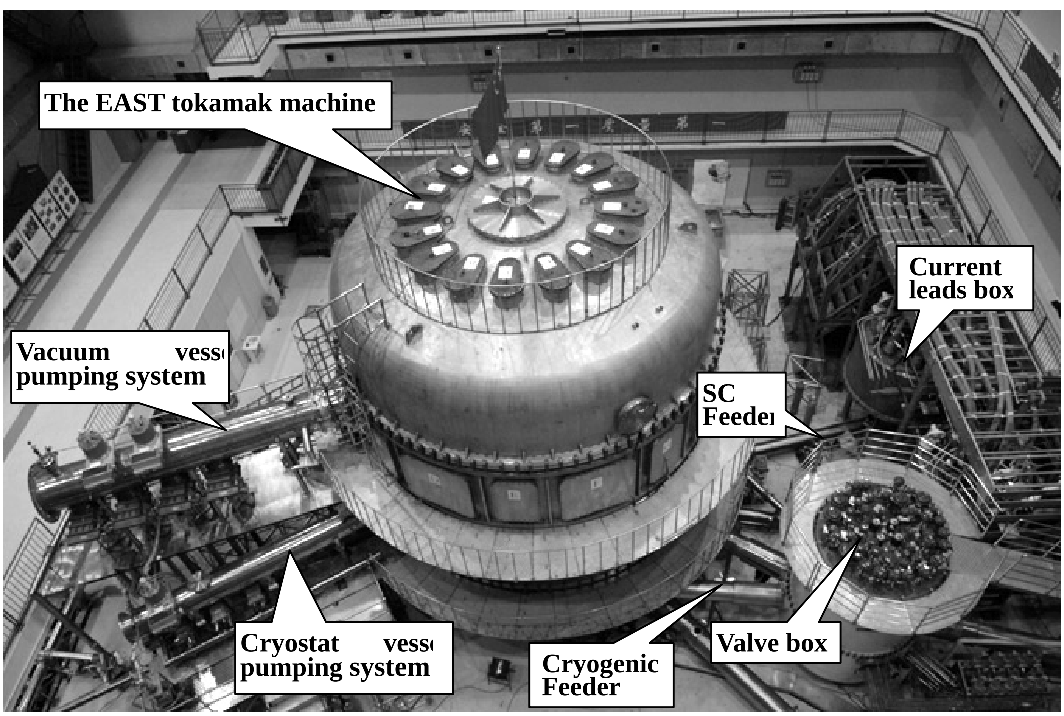

Fig. 1 The EAST superconducting tokamak with the vacuum pumping systems, the feeders and the valve box (1/2 pp)

Table1. The main parameters of the EAST (1/6 pp)

Toroidal Field, B_o	3.5 T
Plasma Current, I_P	1 MA
Major Radius, R_o	1.7 m
Minor Radius, a	0.4 m
Aspect Ratio, R/a	4.25
Elongation, K_x	1.6 - 2
Triangularity, δ_x	0.6 - 0.8
Heating and Driving (in the first phase):	
ICRH	3 MW
LHCD	3.5 MW
ECRH	0.5 MW
Pulse length	1- 1000 s
Configuration:	Double-null divertor Single-null divertor Pump limiter

Table 2. The main parameters of the TF/CS/PF CICC (1/2 pp)

Conductor	TF	CS/Divertor	PF
Configuration	(2SC+2Cu)×3×4×5+1Cu Cable		(1SC+2Cu)×3×4×5+1Cu Cable
Number of SC strands	120		60
Number of Cu strands	120+21		
Diameter of SC strands	0.87mm		
Diameter of Cu strands	0.98mm		0.98mm/0.87mm
Coating thickness	~2μm Pb-30Sn-2Sb	~2μm Ni	~3μm Ni
RRR of Cu strands	> 100		
316LN Conduit thickness	1.5 mm		
Size of CICC	$20.4 \times 20.4mm^2$	$20.35 \times 20.35mm^2$	$18.6\times18.6mm^2$
Void fraction of CICC	35.0%		0.359%
Peak field	5.8 T	4.5 T	1.5 T
Operating temperature	4.2 K (designed value)		
Operating current	14.3 kA	14.5 kA	

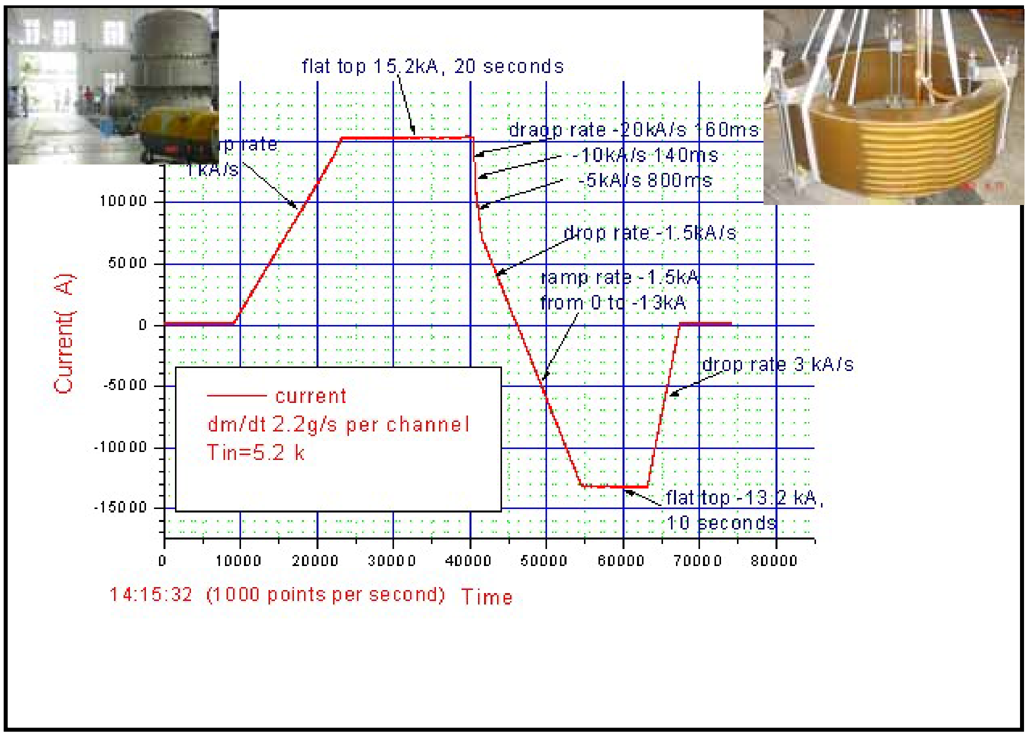

Fig.2 The test result of the first central solenoid coil

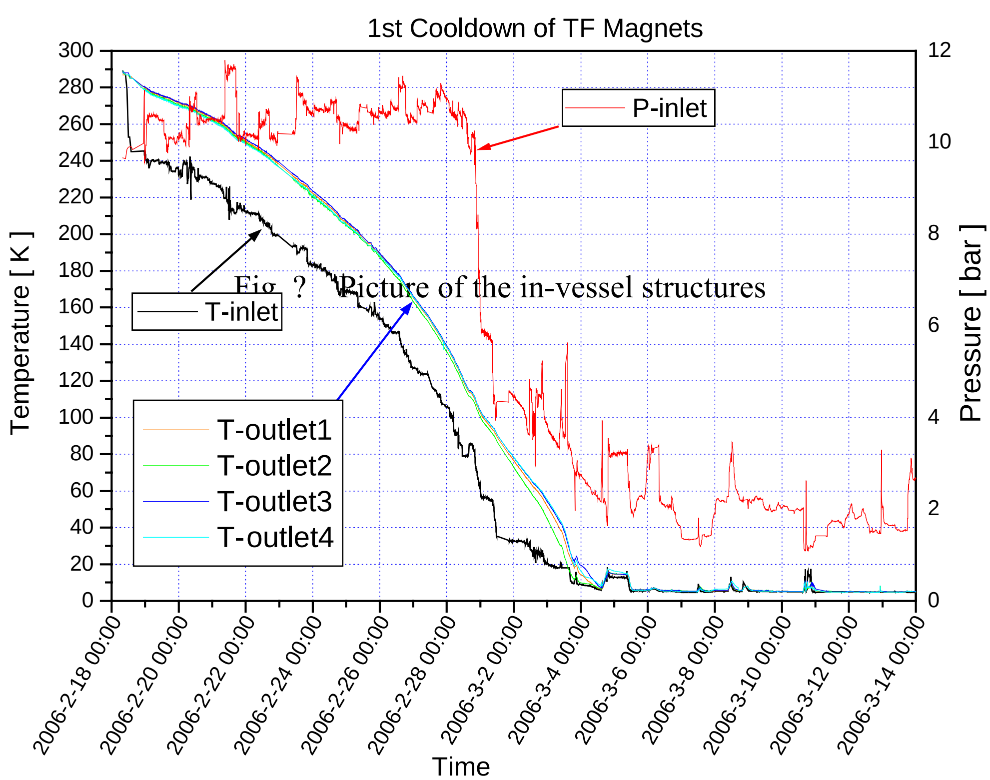

Fig.3 The first cooling down procedure of the TF system during the first commissioning

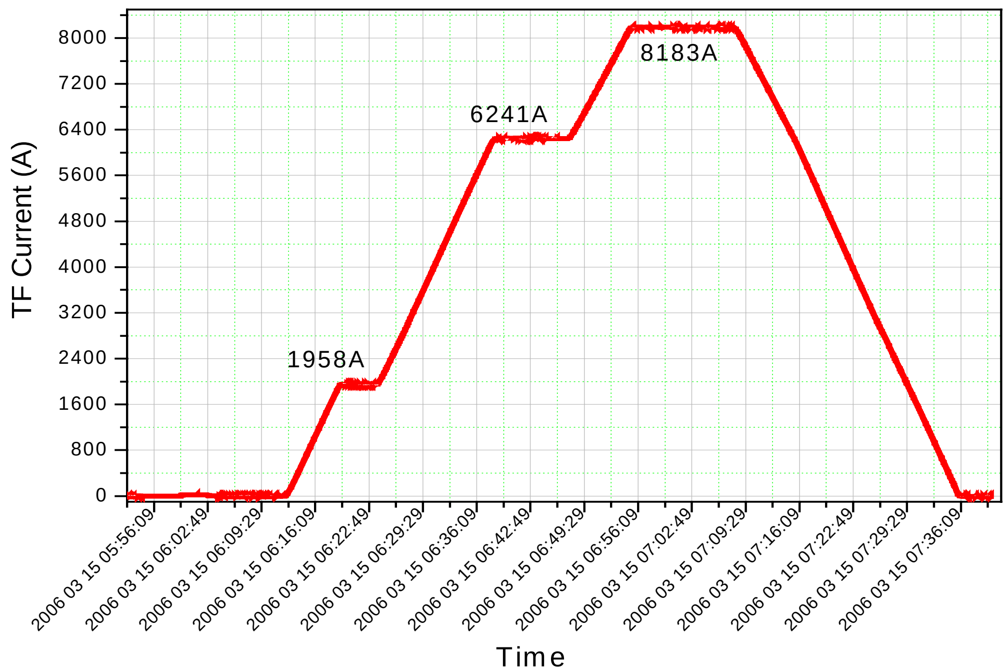

Fig. 4 The 5000s excitation of the TF magnet system (1/6 pp)

Fig. 5 Picture of the in-vessel structures

Fig.6 1st RF plasma

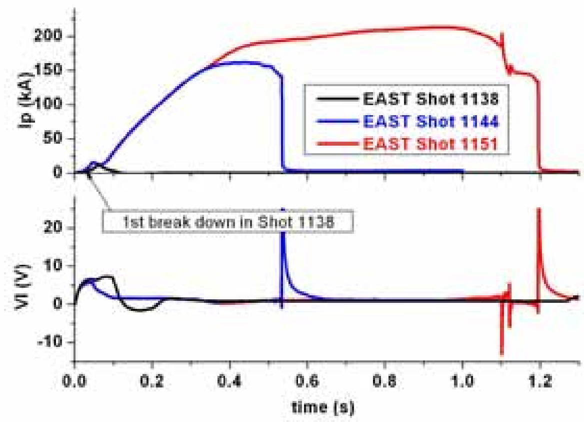

Fig.7 1st break down and following shots with Ip > 150 kA and 220 kA