The Engineering Commissioning of EAST Superconducting Tokomak

P. Weng, Y. Wan, J. Li, S. Wu, D. Gao, Yu Wu, X. Gong, X. Zhang,

H. Bai, P. Fu, X. Liu，Z. Chen, X. Gu, J.Luo and EAST team

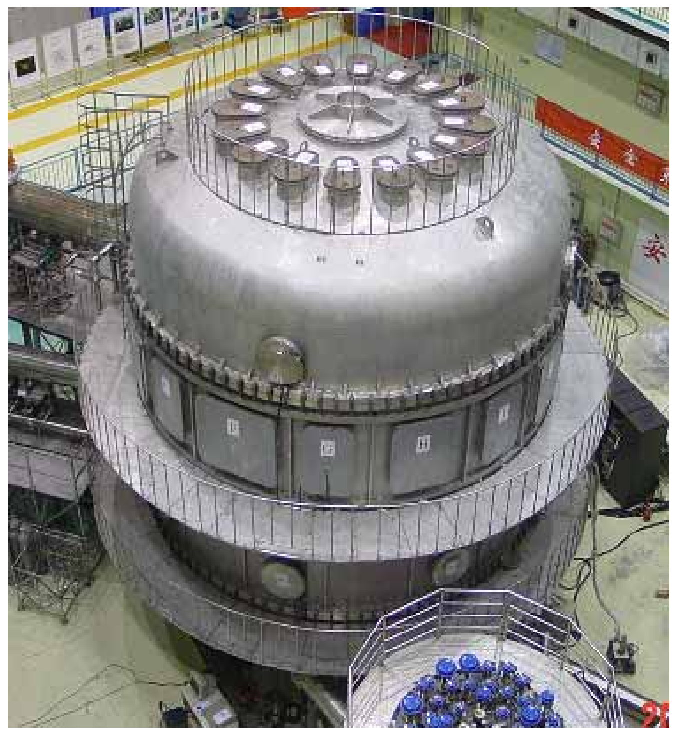
***Abstract*—the assembly of EAST superconducting tokamak is completed in January 2006 and the first cooling down of the magnet system was carried out in Feb-March this year. The main purpose of the experiment is to verify the validity and quality of the design, manufacture and assembly of the tokomak, measure the magnet field configuration and get the most important operation information such as vacuum and leakage rate of the device, the temperature distribution of the magnet, the heat load, the thermal – hydraulic property of the magnet system. At the same time, check the capability and reliability of the related subsystem including the control system, cryogenic system, power supply system, vacuum pumping system and cooling water system.**

The main test items, the process and result of the first cooling down of the EAST device are described in this paper.

***Index Terms*—Cryogenics, Superconducting Magnets Tokamaks, Vacuum system**

I. INTRODUCTION

EAST is a Chinese National Project, the main mission of project is to develop an advanced superconducting tokamak and explore the scientific and technological bases for fusion reactor [1]. The project started in 1998 and after nearly 7 years hard work including 2 years R&D, the most assembling work of tokamak had been completed, actually the installation of superconducting magnet system, the thermal shield, the in cryostat feeders and the cryogenic manifolds as well as the cryostat had been finished; the vacuum vessel was amounted in its position also, however, one section of the vacuum vessel (1/16 of the torus) is not fully welded and the vessel ports had not been assembled and welded yet. In this case, if some serious fault endangering the safety operation, such as cooled leak or insulation damage, would be found during the test, we could dismount the magnet and make a maintenance relative easier. At the same time most of EAST subsystem is ready, and have the possibility to cooldown the device and make an experiment. Therefore, we decided to make the first commissioning in February and March. The main purpose of the commissioning is to test EAST machine and its subsystem's performance and capacities; to acquire the key technical parameters of the machine itself and its sub-systems and to validate the reliability of the interlock, safety and protection system. The first commissioning of EAST was carried out in February – March 2006. It consists of leakage testing, pumping down, cooling down all coils, current leads, bus bar and the thermal shielding and exciting the coils. Fig.1



shows EAST device. Fig. 1 EAST device

II. THE MAGNET, POWER SUPPLY AND COOLING SCHEMA

A. The TF magnet

The TF magnet system is consists of 16 D-shaped coils [2], providing a field of 3.5T at the plasma radius of 1.75 m with a peak field of 5.8T at the coils. The total storage energy is 300 MJ and the total weight of the coil and its case is 175 tons. Fig.2 shows the top view of EAST TF and PF magnets.

The cable in conduit conductor is chosen for EAST TF and PF magnet [3], Each TF coil contains 12 pancakes and each double pancake is one cooling circuit with a length of 200 meters. There are 96 cooling loop in total and all of them are

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P. Weng is with the Institute of Plasma Physics Chinese Academy os Sciences, Hefei, Anhui 230031,China Tel.: +86-551-5591609; Fax: +86-551-5591310. Email: pdweng@ipp.ac.cn.

connected in parallel. The cooling loops are divided into 4 groups, and the mass flow rate of the 4 groups could be adjusted by 4 control valves. One helium pump is used as a circulator, provides the supercritical helium to cool the TF coils; and the maximum mass flow rate of the pump is 260 g/s. One oil ring pump is used to reduce the helium pressure and obtain the 3.5 K helium in a sub-cooler, which is used for cooling down the supercritical helium again, so that the TF coils could be operated at 3.8 K.

The TF coil cases are welding structure. Stainless steel tubes are embedded and soldered all along the side surfaces of the cases. The cooling channel on each coil case is connected into one cooling loop and the 16 of cooling loops are connected in parallel. The loops are divided into 4 groups same as TF coils. One helium pump, which can provide 320 g/s supercritical helium, is used for the TF case cooling.

The 16 TF coils are connected in series and feed by a TF power supply

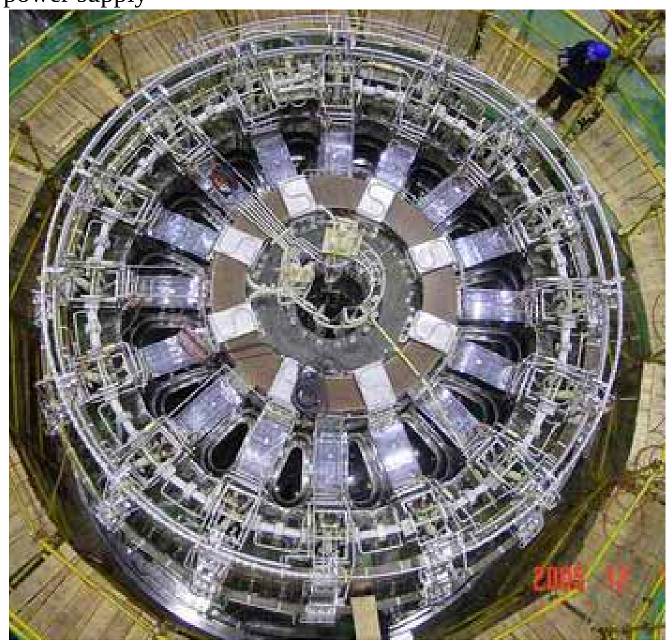

Fig.2 the top view of EAST magnet system

B. *PF Magnet*

The PF system [4] consists of a central solenoid (CS) and three pairs of PF coils located symmetrically along the vertical axis of the equatorial plane of the device.

All PF coils are circular coil. The six inner PF coils form the CS assembly. each coil is vacuum pressure impregnated with epoxy resin. The PF coils are mounted on the TF coil cases to support the electromagnetic forces and gravity loads.

Each CS coil contains 5cooling loops; another 3 type of PF coil contain 14, 10 and 8 cooling loops with different lengths individually. There are 94 PF cooling loops in total and the required mass flow rate for each cooling channel is not less 2 g /s, however, the supercritical helium flow from refrigerator is limited in 110 g /s only. In order to satisfy the required mass flow rate for all loops, the PF coils are divided into two groups, and the two groups are connected in series when the cooling loop within one group are connected in parallel. After cooling the first group of PF coils, the helium will be cooled again in a sub-cooler and then cool the second group of PF coils.

There are 12 sets of PF power supply system, each PF coils can be feed with different current individually.

C. *Thermal Shields*

The thermal shields comprise of the vacuum vessel thermal shield (VVTS), the cryostat thermal shield (CTS) and the ports thermal shield (PTS) [5]. The VVTS is consisted of 16 sectors and the CTS is divided into three parts: upper cap, middle cylinder and bottom platform, each part consists of 8 sectors. The PTS connecting VVTS and CTS are bolted on them. The Total surface area of thermal shield is 310 m^2. All of the thermal shields are double-wall structures, 19×19 mm^2 cooling tube is sandwiched between two 3 mm thick stainless steel panels. The cooling loops of the thermal shield are divided to two groups, the first one consist of VVTS and PTS, 32 parallel cooling circuits in total; the second one is CTS with 24 parallel cooling circuits. The VVTS and PTS are cooled by 60K, 110g/s helium gas from the refrigerator at first and the return gas will be cooled down to 80 K in a liquid nitrogen sub-cooler and used for CTS cooling.

III. THE CRYOGENIC SYSTEM

The cryogenic system includes the compressor station, a 2 kW/4.5 K refrigerator and the helium distribution system [6].

The compressor station consists of seven screw compressors arranged in two stages; a four stages oil removal system and a 9000Nm^3 helium recovery system. It provides 480 g /s helium with pressure of 20 bars. The helium refrigerator is designed at the capacity of 1050 W / 3.5 K + 200 W / 4.5 K+13 g / s Liquid helium + 13 KW / 80 K, according to the estimation of the heat loads. The refrigerator provides supercritical helium to cool magnets, supporting structures, superconducting bus-bar and current leads; It also provides cold helium flow to cool thermal shields. The helium distribution system is composed of the control valve box with 46 valves, sub-cooler, circulating pumps and cryogenic transfer lines which distribute 4.5K Supercritical

Fig.3 the refrigerator

helium and 80K helium to the different components of the tokamak. A 10000 L Dewar is used as the storage of liquid helium and regulates cooling capacity day and night. Figure 3 shows the refrigerator.

IV. THE CONTROL AND DATA SYSTEM

The control and data system of EAST is designed as a Distributed Control System (EASTDCS), including many subsystems to provide various functions of supervision, remote control, real-time monitoring, data acquisition and data handling. the real-time data handling and analysis, along with a significant control capability is required, The EASTDCS consist of Main control system (MCS), Engineering control system (ECS), and Diagnostics and data system (DDS) The MCS is a key component of the EASTDCS. It plays the most important role in the control and monitoring functions of the whole system, including the time-synchronizing system, a safe-protection interlock system (using a Programmable Logic Controller (PLC)), and a real-time plasma parameter-display system.

The ECS system will incorporate an array of network-based programmable controllers, The DDS system handles all settings and real-time modifications for subsystems, The plasma control system of EAST (EAST PCS) [7] is designed as a PC cluster, which was design by the DIIID PCS team in General Atomics, would be responsible for poloidal field (PF) system and density control including equilibrium shaping/position and stability control, plasma current control, gas valve actuation.

V. EXPERIMENT AND TEST RESULTS

The pumping system started on Feb.7 and successfully operated through the whole commissioning experiments. The highest vacuum of cryostat reached 3.8x10^{-5}Pa that is above the operation requirement of 2x10^{-4}Pa.

The leakage of in cryostat cooling circuits including the superconducting magnets, busbar and cryogenic manifolds are tested carefully with 0.4 M Pa pressure in cooling loops. One minor leak were found in a sector of CTS bottom platform, the leakage rate is 4.5×10^{-4} Pa.m^3/s at room temperature, which is acceptable for the operation, while the leakage rate of all magnets, superconducting busbar and cryogenic manifolds is less than 5.6×10^{-7} Pa.m3/s. The leakage of cryostat is 1.2×10^{-4} Pa.m3/s.

The cryogenic system started on Feb.10. Various operation mode of cryogenic system has been explored and optimized to the design state. The refrigerator power reached 2.4 kW / 4.5 K, which is 20 % higher than designed value.

The device cooldown started on Feb. 18. The temperature differences between all parts in cryostat are controlled less than 50 K during the cooling down. After 14 days cooling, all of coils (215Tons cold mass in total) were cooled down to 4.5 K on March 4. The helium circulators were tested and reached their nominal value, and average mass flow rate in each cooling channel was above the design value. Fig. 4 shows the inlet and outlet temperature of TF coils during the first cooling down. There are 12 sets of PF power supply system and one TF supply system, all of them have been installed in February, however, only TF power supply system and 4 sets of PF power supply system were fully ready at the time of commissioning.

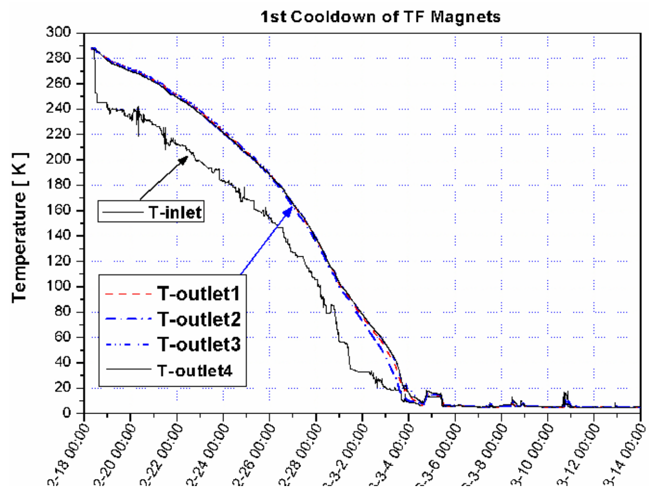

Fig.4 the first cooldown of the TF magnets

Therefore they were connected to different coils and have been tested successfully. The results show that the systems are satisfactory and reliable.

All coils were energized with different current and ramping rates. The longest TF duration was 5000 seconds, and the highest TF current was 8200A, which is about 60% of nominal value, and the corresponding magnetic field at plasma center is 2 T. Fig. 5 shows the energizing of the TF magnets.

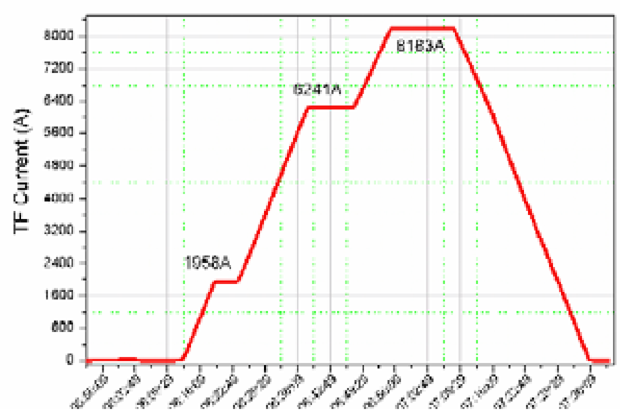

Fig. 5 TF magnet energizing

All the PF coils were tested. However, due to the unfinished vacuum vessel and the possible induced current and electromagnetic forces on it, the current of PF coil was controlled under 3 kA. Individual coil, different two PF coils, 4 PF coils, 4PF+TF coils have been tested. A total 260 shots have been fired for quench testing, joint resistance and magnetic configuration measurements. Quench detection system have obtained a large amount of data which is very useful for getting reliable quench protection. Nine pairs of commercial current leads and four pairs HTS current leads worked properly and passed the test. The coil joint resistance has been measured; the preliminary results show that the 87 joints resistances are below 10 nΩ, though the accuracy of the measurement is relative low due to the small PF current. The magnet instrumentation has been tested. Most of the temperature sensors worked normally, while few sensors were out of order and need to be replaced after the experiment and part of sensors need to be calibrated

The central control system, data acquisition system, plasma control system, the interlock and safety protection system have been tested.

At the same time, a few problems have been found which indicates the further efforts should be made to complete the construction of EAST with high quality.

VI. FURTHER WORK AFTER FIRST COMMISSIONING

The device was warmed up after the first cooldown, and the leakage on the CTS was located by careful leak hunting and the injured cooling channel was replaced by the redundancy cooling tube on the sector. The device assembling, which was not completed before the commissioning, was continued. The last welding of the vessel torus has been completed and 48 ports were assembled and welded on the vessel. After that, the in vessel components including the first wall, the diverter, the electromagnetic measurements, the feed back control coils moveable limiter, ICRF and LHCD antenna as well as few diagnostic instruments are installed in the vessel. Fig. 6 shows the installation of in vessel components.

In parallel, the improvement of sub-system started since the end of March and has been completed in beginning of August.

Fig.6 In vessel components installation

The tokamak has been cooled down again since Aug. 1st, the device and all subsystem are fully tested. The TF magnet was energized to14.3 kA, The PF system can provide more than 10 volt-second flux swing. The first plasma with plasma current up to 220 kA was successfully achieved on September 26, 2006 on EAST see Fig.7

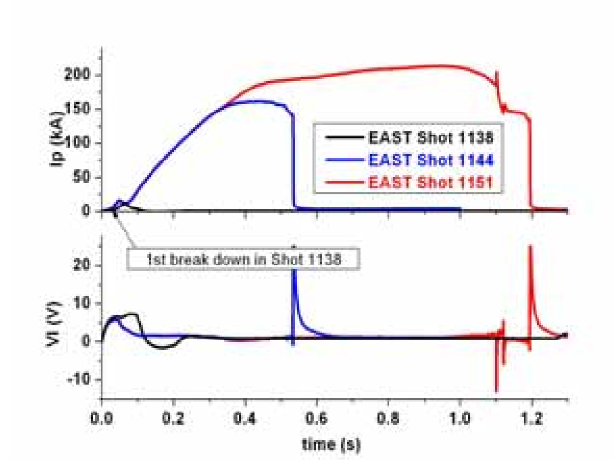

Fig.7 EAST first plasma

VII. SUMMARY

The results of EAST commissioning show that the EAST machine and its sub-systems have been successfully built, and will start experiment this year when it will provide fusion community a great facility for steady state diverter plasma research.

ACKNOWLEDGMENT

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