HT-7U* Superconducting Tokamak: Physics design, engineering progress and schedule

Y.X. Wan 1), P.D. Weng 1), J.G. Li 1), Q.Q. Yu 1), D.M. Gao 1), HT-7U Team
1) Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, P.R. China
e-mail contact of main author: wanyx@mail.ipp.ac.cn

Abstract. The superconducting tokamak research program was begun in China at the Institute of Plasma Physics in 1991. The program includes the existing superconducting tokamak HT-7 and the next new superconducting tokamak HT-7U, which is one of the national key research projects in China. With an elongated cross-section, divertor and higher plasma parameters, the main objectives of HT-7U are the wide investigation of both the physics and technology for a steady state advanced tokamak as well as the investigation of power and particle handling under steady-state operation conditions. The physics and engineering design have been completed and significant progress on R&D and fabrication has been achieved. HT-7U will begin assembly in 2003 and the first plasma is planned for around the end of 2004. The name **HT-7U*** will soon be changed to **EAST** (Experimental Advanced Superconducting Tokamak).

1. Introduction

The population of China is around 1.3 billion now and will be 1.5-1.6 billion in 2050. The average energy consumption in China is less than 1/2 of the world level and coal still is the main energy resource, but the per capita level of the coal is very poor in comparison. China will face a serious energy shortage and pollution in the near future. Fusion research in China of course should be aimed to solve the future energy problem. Because great progress on tokamaks has been achieved, the superconducting tokamaks are a success and several ways to drive non-inductive plasma current have been obtained, the Steady-State Advanced Tokamak (SSAT) can be build. SSAT should be a superconducting tokamak and it is possible that the SSAT can develop to be a future tokamak reactor. Therefore the superconducting tokamak research program was begun at the Institute of Plasma Physics (ASIPP) in 1991. The program includes the existing superconducting tokamak HT-7 [1], the approved national project for the next superconducting tokamak HT-7U [2] and a possible proposal for a test tokamak reactor [3] in future.

2. Physical Requirements and Design

HT-7U is a national key search project approved in 1997-1998. The main objective of HT-7U is the wide investigation of both the physics and technology for a steady-state advanced tokamak as well as the investigation of power and particle handling under steady-state operation conditions.HT-7U will make an contribution to a future Steady-State Advanced Tokamak Reactor (SSATR). It should be a full superconducting tokamak with sufficient inductive current, CW non-inductive current and heating systems. It should have a large operation space, flexible J(r) and P(r) control, reliable and quick plasma position and shaping control, standard PFC with changeable tiles, a divertor for power and particle handling and advanced diagnostics. Because of budget limitation there are two phases for HT-7U: the first phase, with lower plasma parameters and with only Ohmic and RF heating; and the second phase, with higher plasma parameter and with both RF and NBI heating. The calculations and design for the operate regions in the firstphase, RF heating, LHCD, diagnostics, safety, environment, the flexible equilibrium configuration and double null divertor have been completed. Table1 summarizes the main parameters. Fig.1 shows the four typical configurations and divertor design and Table 2 shows the possible plasma parameter regions which HT-7U can achieve under different operation modes in the first phase.

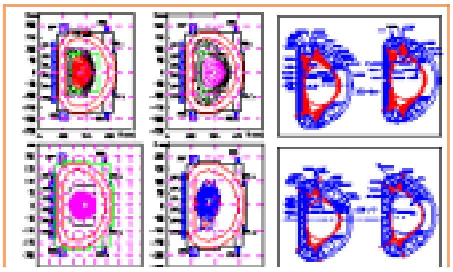

FIG. 1. Typical configuration and divertor design

Table 1: Main parameters of HT-7U

Toroidal field, B_T(T)	3.5
Plasma current, I_p(MA)	1.0
Major radius, R(m)	1.75
Minor radius, a(m)	0.4
Elongation, K	1.6-2.0
Triangularity	0.4-0.8
Shape	Double- and single-null
Ion cyclotron, P_{ICRF}(MW)	3.0
Lower hybrid, P_{LH}(MW)	3.5
Electron cyclotron, P_{EC}(MW)	0.5
Pulse length(s)	1000
Plasma species	Hydrogen and/or deuterium

TABLE 2: 1 MA DEUTERIUM OPERATION

(B_t = 3.5 Tesla, Ip = 1 MA; q* = 3.4, q_{95} = 5.1)

	H = 1.5	H = 2	H = 3
τ_E (ms)	95	127	191
<n T> (10^{19} m^{-3}keV)	23	31	46
W (MJ)	0.58	0.77	1.2
β_p	0.76	1.0	1.5
f_b (I_b / I_p)	0.18	0.25	0.37
β_N	1.0	1.4	2.1
β (%)	0.74	0.98	1.5

TABLE 3: 0.4 MA DEUTERIUM OPERATION

(B_t = 2 Tesla, Ip = 0.4 MA; q* = 4.9, q_{95} = 7.7)

	H = 1.5	H = 2	H = 3
τ_E(ms)	35	46	69
<n T> (10^{19} m^{-3}keV)	8.1	11	16
W (MJ)	0.21	0.28	0.42
β_p	1.7	2.3	3.4
f_b (I_b / I_p)	0.41	0.55	0.82
β_N	1.6	2.2	3.2
β (%)	0.81	1.1	1.6

TABLE 4: 1.5 MA DEUTERIUM OPERATION

(B_t = 4.0 Tesla, Ip = 1.5 MA; q* = 2.6, q_{95} = 3.9)

	H = 1.5	H = 2	H = 3
τ_E(ms)	149	199	298
<n T> (10^{19} m^{-3}keV)	35	46	69
W (MJ)	0.89	1.2	1.8
β_p	0.52	0.69	1.0
f_b (I_b / I_p)	0.13	0.17	0.25
β_N	0.93	1.2	1.9
β (%)	0.87	1.2	1.7

It is planned in the second phase that B_T will be increased to 4.0 T, I_p to 1.5 MA and 15 MW neutral beam will be added. Two tangential windows have been designed for NBI.

3. Features of the Engineering Design

Sixteen superconducting TF and twelve PF coils are symmetrically located on the plasma mid-plane. Six inner PF coils constitute the CS assembly. A vacuum vessel with racetrack-shaped horizontal ports and bathtub-shaped vertical ports are located in the bore of the TF coil. Two 80 K thermal shields cover all the superconducting magnets. A cryostat encloses all of the superconducting coils with radiation shields, vacuum vessel and support structures. The superconducting magnet system, vacuum vessel and thermal shields are supported on the cryostat independently. Analysis and calculation of the engineering design indicated that the structures of the main parts of the device satisfy the physical requirements and the engineering reliability. The cross-section view of the HT-7U device is shown in Fig.2. The TF magnet system consists of 16 D-shaped coils; each coil is composed of two packs of winding which are wound separately. NbTi Cablein Conduit Conductor (CICC) with segregated copper is chosen for the TF magnet. The inner leg of the TF coil cases is designed to be wedge-shaped to form a vault withstanding the magnetic centripetal forces. Vacuum pressure impregnation will be adopted to enhance the insulation and integrity after setting the coil into the case. Table 5 shows the parameters of the TF magnet.

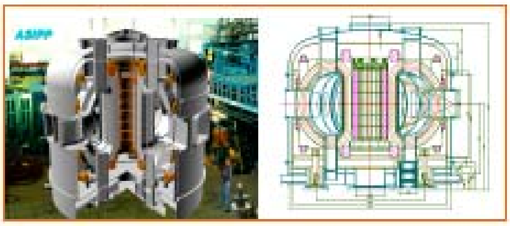

FIG. 2. HT-7U tokamak device.

TABLE 5: PARAMETERS OF THE TF COIL SYSTEM

Maximal field at coil	5.8 T
Total turns	16 × 130
Coil size (D Shape)	3.52 × 2.51 m
Winding type	6 pancakes
Conductor size	20.4 ×20.4 mm
Length of each coil	2 × 593.5 m
Length of cooling channel	201 m
Operating current	14.3 kA
Operating temperature	3.8 K
Total storage energy	298.5 MJ

The PF magnet system [4] consists of three pairs of central solenoid coils and four pairs of poloidal coils. They are placed symmetrically about the device horizontal mid-plane. The flux swing of the PF magnet will be 10 v.s and it could induce 1 MA plasma current and sustain it up to 10 seconds without auxiliary current drive. The CICC with NbTi and segregated copper is chosen for the PF magnet. The vacuum vessel has a full welded double wall structure. There are 16 horizontal ports and 32 vertical ports for diagnostics, auxiliary heating and current drive. The divertor and limiter are covered by graphite and CFC tiles. There are passive stabilizers and fast feedback control coils in the vessel. The armor electrical heater can bake up the vessel and first wall up to 200^{o}C and 350^{o}C respectively. The first wall components and vessel wall will have active cooling. The cooled components for the cryogenic system [5] are the TF and PF magnets, support structure, 7 pairs of current leads, superconducting bus line and thermal shield. The cooled mass is around 165 tons at 3.8-4.5K and 20 tons at 80K. The estimated heat load is about 890W/4K + 7.5g/s and 30kW/80K for normal operation.110g/s-3.8K supercritical He flow for the PF coil cooling and 260g/s-3.8K supercritical He flow for the TF winding and coil case cooling will be used. 110g/s-60K He flow will be used for the thermal shield. The cryogenic system consists of a 2kW/4.4K+13kW/80K refrigerator, 260g/s-4bar He pump, 1000L-3.8K sub-cooler, 10000L-4.5K liquid He tank, gas storage system and compressor station. The compressor station and gas storage system have already been installed; 2kW/4.4K+13kW/80K refrigerator has been designed and will be fabricated soon. The power supply consists of TF (TFPS), PF (PFPS)[6] and fast plasma position control system (FPPCPS). A thyristor converter has been designed for AC/DC conversion in TFPS and PFPS. Multi-stage forced commutation techniques and thyristor DC circuit breakers are applied in PFPS to reduce the peak power. Thyristor and explosive actuated DC circuit breakers have been developed for quench protection. high frequency H-bridge inverter for FPPF is under construction and testing.

4. Schedule and Present Status of the Project

The project was approved as one of the national research projects selected from more than 100 proposed projects in 1997 by the Chinese government. Both the physics and the engineering designs of HT-7U have been completed. Significant progress in the R&D and fabrication has been achieved since 1999. The work was mainly performed by ASIPP and focused on CICC design and fabrication; setting up the winding machine and winding the D-shaped coil; setting up the test facility; design, fabrication and testing of the CS model coil; and some key technologies. All of the R&D and fabrication activities have been successful up to now. Fig.3-Fig.9 show some of this progress. Fabrication of all of the magnets and final assembly of the tokamak will be done by our workshop. The total budget of the project is only about US $20 million but significant progress of the project has been achieved through the great effort of our workshop as well as wide international collaboration.

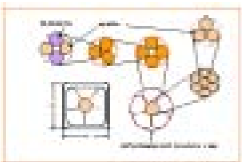

FIG. 3. CICC design.

FIG. 4. 600 m CICC.

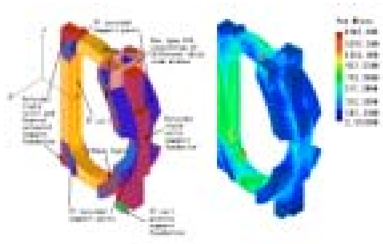

FIG. 5. Analysis of the TF magnet.

FIG.6. Full size TF coil.

FIG.7. Test facility.

FIG.8. CSM coils.

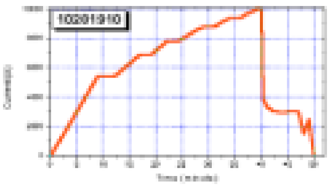

FIG.9. Test result of CSMC.

The significant progress of both the pre-physics experiments and the development of technologies such as RF, cryogenic, control systems and first wall material have been also achieved on the HT-7 superconducting tokamak[7,8]. Most of the R&D and fabrication will be done from 2000 to 2003 and the final assembly will begin in 2003. It is hoped that the first plasma can be obtained around the end of 2004.

5. Summary

China will face a serious energy problem in the near future. The main fusion research activities in China should be more closely aimed at solving the problem. A possible solution is to develop SSATR via a superconducting tokamak, and therefore the superconducting research program in ASIPP is a long-term program, which includes HT-7, HT-7U and a future superconducting test reactor. Progress of the HT-7U project on design, R&D and fabrication has been achieved and it is planned to obtain the first plasma around the end of 2004. Wide international collaboration is welcome both in the construction phase and in the experimental phase in the future.

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