J. Plasma Fusion Res. SERIES, Vol. 5 (2002) 106–111

Magnetic Confinement Fusion Research in China

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(Received: 11 December 2001 / Accepted: 8 May 2002)

Abstract

China will face to serious energy problems in near future and the magnetic confinement fusion research is getting more support. SWIP and ASIPP are two largest research centers for the research. Five tokamks (HT-7, HL-1M, HT-6M, KT-5 and CT-6) are running and many experimental progresses have been achieved. Three new projects have been approved and the new facilities (HT-7U, HL-2A and SUNIST) are under construction.

Keywords:

energy, China, magnetic confinement fusion research, tokamak

1. Introduction

With the rapid socio-economic development during last 10 to 15 years in China the magnetic confinement fusion research is getting more and more support via different channels by the government. Three new projects have been approved and the new facilities are under construction. The research budget for magnetic confinement fusion research is increasing smoothly year by year. The number of graduated students also increases rapidly with the reformation of education system in China. Because China will face to more serious problems on the shortage of energy and the pollution of the environment in near future with the rapid economic development, the government now is very interested in the prospect of magnetic fusion research, especially the tokamak research. The government is also interested in the further information about ITER. Many high level officers of the government have visited both SWIP and ASIPP. Two institutes are making effort together to promote China to participate in the ITER program by some way if it will be constructed in the near future.

2. Organization and Facilities

Southwest Institute of Physics (SWIP) which now belongs to the National Committee of Defense Sciences and Industry of China and Institute of Plasma Physics (ASIPP) which belong to the Chinese Academy of Sciences are two largest research centers for the magnetic confinement fusion research in China.The main facility in ASIPP is the medium sized superconducting tokamak HT-7 (Fig. 1). Its main purpose is to explore high performance plasma operation under steady-state condition. The machine runs normally with I_p = 150 KA, B_T = 2 T, R = 122 cm and a = 27.5 cm [1,2]. Another small tokamak HT-6M with I_p = 100 kA, B_T = 1.5 T, R = 90 cm, a = 20 cm in ASIPP is used to study ICRF and transport. The facility in SWIP is tokamak HL-1M (Fig. 2). It is a medium sized tokamak with R_0 = 1.02 m, a = 0.26 m and B_T = 3 T in circular limiter configuration. Its objectives are to conduct experiments on high power auxiliary heating and current drive and to explore new fueling techniques in order to develop the physics and technology for next generation tokamak [3].

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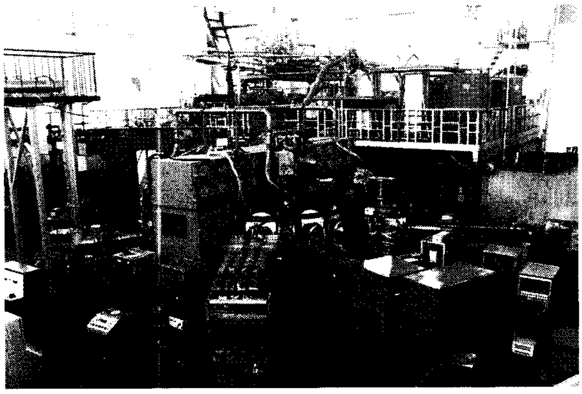

Fig. 1 HT-7 superconducting tokamak

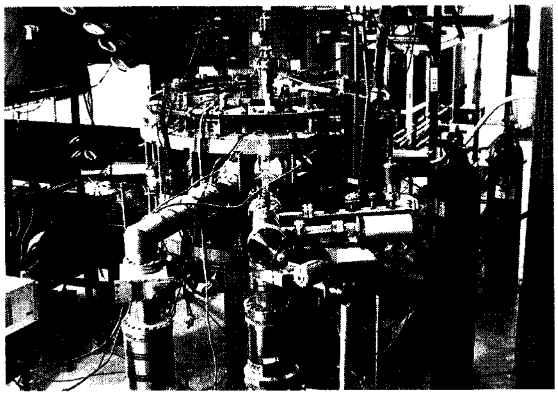

Fig. 3 KT-5 tokamak in USTC

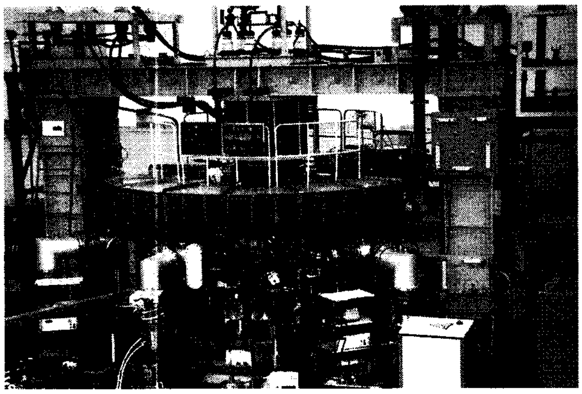

Fig. 2 HL-1M tokamak in SWIP

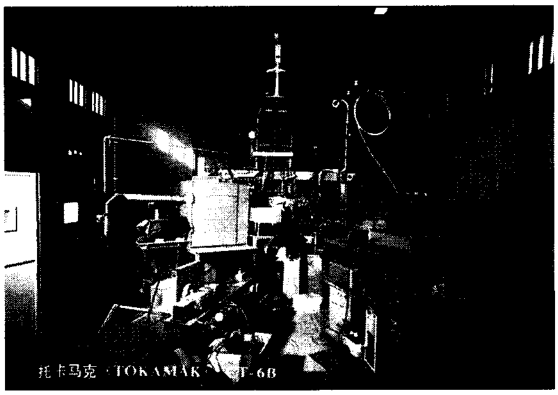

Fig. 4 CT-6B tokamak in IPCAS

Other two small tokamaks are KT-5 (Fig. 3) in the University of Sciences and Technology of China (USTC) in Hefei and CT-6B (Fig. 4) in the Institute of Physics, Chinese Academy of Sciences (IP/CAS, Beijing). Both of them are operated for edge turbulence/ transport study and alternative concept development.

3. Main Experimental Progresses on Existant Devices

3.1 HT-7 Tokamak Experiments

The stable continuous operation for 1~3 months during each campaign has been achieved on HT-7 superconducting tokamak [1,2]. A new type of wall conditioning and Boronization and Siliconization using ICRW instead of the glow discharge or Taylor discharge have been well developed. It is easy to get high quality film of Boron or Silicon with very high efficiency to control impurity and to decrease the loop voltage and recycling. The perfomance of discharge was improved significantly and the stable region in the Hugill diagram was extended by the new type of wall conditioning and Boronization (Fig. 5) [4].

For the long pulse discharge and future steady-state operation on supercoducting tokamak the LHCD system with 1.2 MW (CW) and 2.45 GHz have been bult and tested. Using these system the long pulse discharges with higher performace and plasma current fully driven by LHW for more than 3 seconds have been achieved (Fig. 6). The ramp-up of plasma current by LHW, which will be very important to set-up the plasma current by a non-inductive current on superconducting tokamak, was also acheived (Fig. 7) [5].

Effective IBW heating with 300 kW (CW) RF system has been demonstrated (Fig. 8) [6]. Gas puffing, pellet injection and supersonic beam injection have been used for plasma fuelling and density control. A real-time multi-variable control system has been developed for the fast equilibrium control. Combining above efforts the

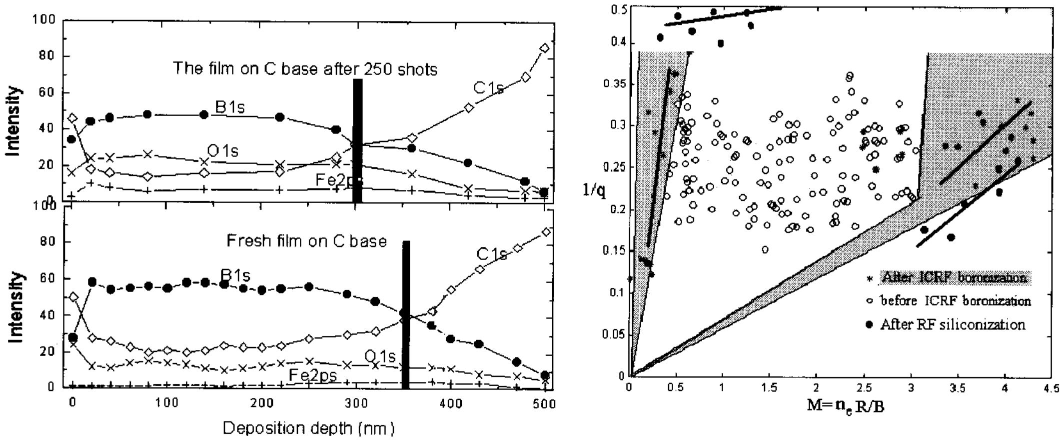

Fig. 5 High efficiency and quality Boronization using ICRW and Extended Hugill diagram

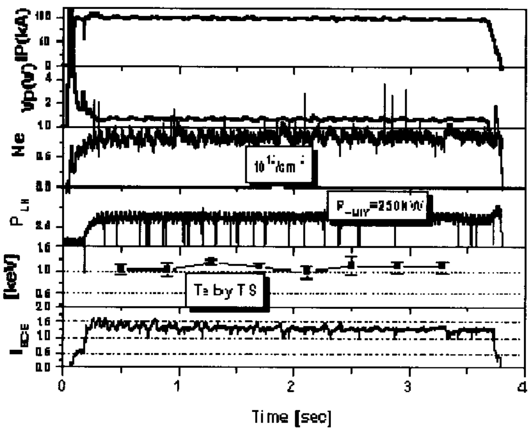

Fig. 6 Long pulse high performance plasma discharge sustained by LHCD

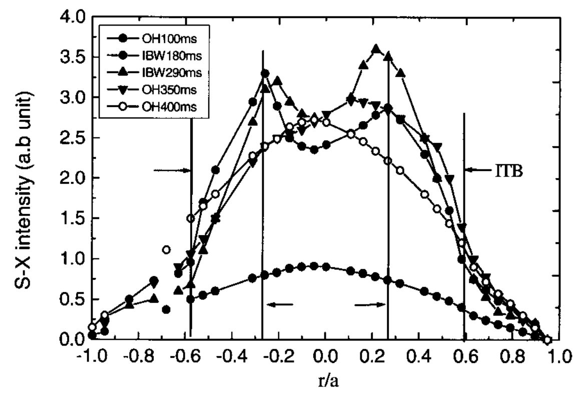

Fig. 8 Plasma off-axis heating by IBW forms a ITB-like profle in SX emission, $\Omega_H \sim 0.27$

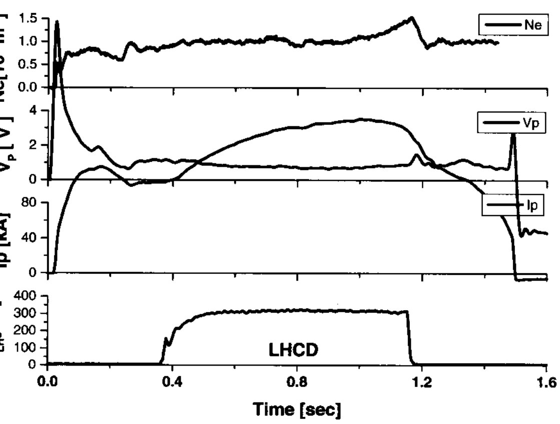

Fig. 7 Plasma current ramp-up by LHCD

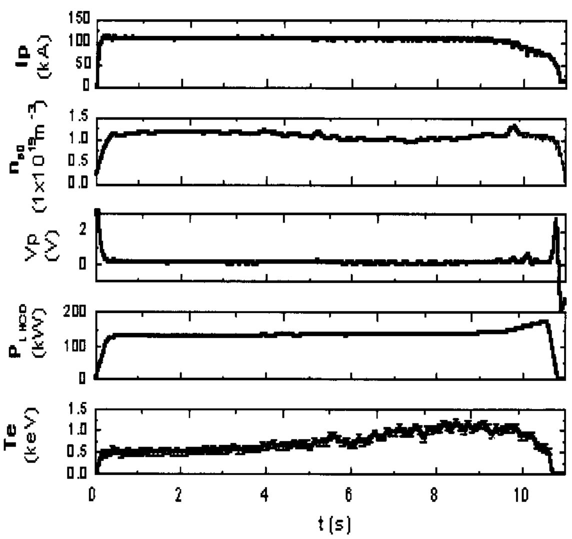

Fig. 9 Repeatable 10 seconds discharges

long pulse discharge with several seconds and the longest one with 10.7 seconds on HT-7 can be easily achieved (Fig. 9).

3.2 HL-1M Experiment

On HL-1M, plasma performance was greatly improved through the use of boronization, siliconization and lithiumization [3]. The maximum parameters obtained in HL-1M ohmic heated plasmas are: $I_P = 320$ kA, $n_e = 8 \times 10^{19}\,\mathrm{m}^{-3}$, $B_T = 2.8$ T. ICRF at a power level of 0.3 MW, NBI at a power level of 0.4 MW, ECRH at a level of 0.30 MW and LHCD at a power level of 1 MW have been carried out. By the off axis ECRH, the electron temperature increased from 450 eV to 750 eV and the MHD activities were supressed significantly. The double sawtooth in soft X-ray radiation were observed (Fig. 10) [7]. The new fueling techniques with pellet injection and supersonic molecular beam injection (SMBI) were also employed to significantly improve the energy confinement time and density limit. The fuelling of SMBI has been improved in the HL-1M tokamak recently and a simple model of "cold injection path" during the SMBI has been proposed, which is supported by measurements of the edge temperature (T_e), density (n_e), H_a intensity profile (OF9, OF11) and HCN average electron density as shown in Fig. 11 [8].

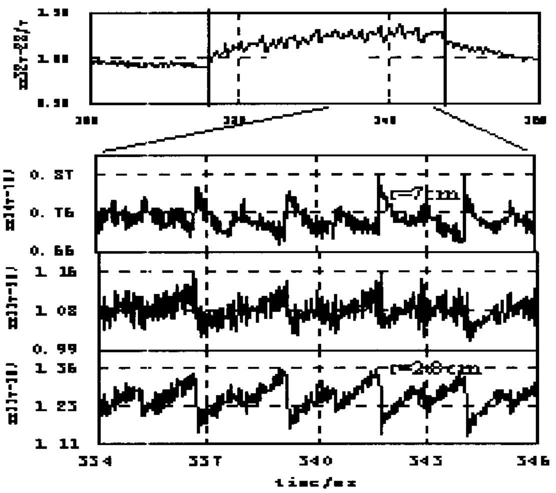

Fig. 10 Double sawtooth in soft X-ray radiation during ECRH

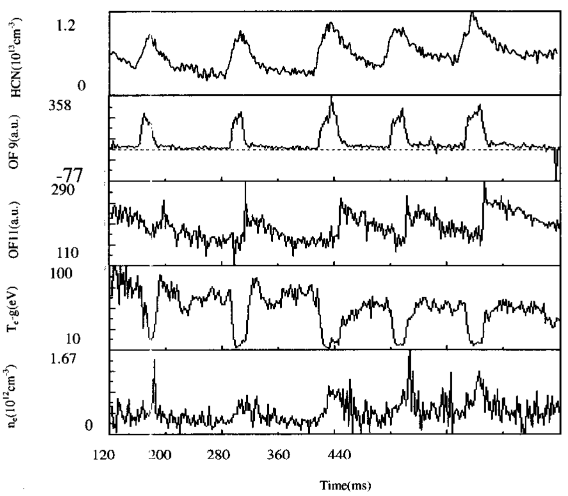

Fig. 11 Edge Plasma Parameters during SMBI

3.3 KT-5C Experiment

On KT-5C tokamak ($R = 32.5$ cm, $a = 12.5$ cm, $I_p = 10$–20 kA) the interesting results of fluctuation and transport investigation in the edge of plasmas have been obtained. The suppression of the turbulent transport with the change of the radial electric field E_r induced by the biased electrode is observed. It is found that the poloidal flow contributes to the main part of the E_r. The change of the poloidal flow has a lead of about 20 μs to the formation of E_r as shown in Fig. 12. It suggests that a radial current responding to the biasing voltage drives a poloidal flow, which in turn drives the radial electric field.

3.4 CT-6B Experiment

In the AC operation experiments on CT-6B tokamak, the plasma current profile and the flux surface during the current reversal have been reconstructed and a novel method of the electron cyclotron wave current startup was demonstrated (Fig. 13).

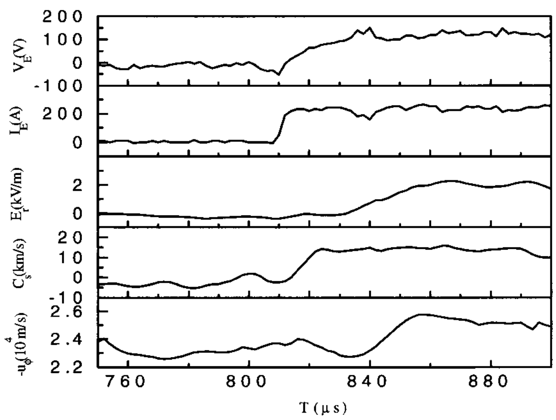

Fig. 12 Temporal evolution of the electrode voltage V_e and current I_e, radial electric field E_r, poloidal ratio ∂C_s and toroidal velocity u_ϕ at $r = 7.5$ cm.

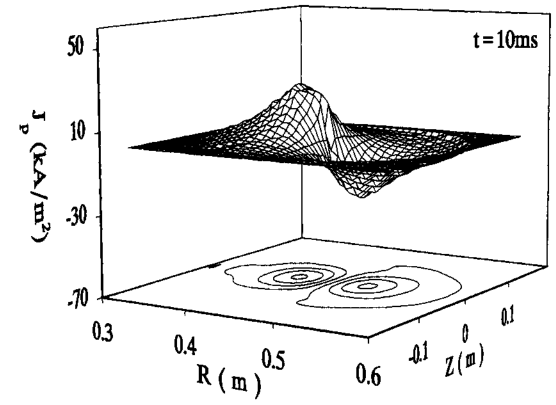

Fig. 13 The plasma current distribution during the total current passes zero in CT-6B tokamak.

3. New Projects and Facilities which is Under Construction

Chinese government has approved a new superconducting tokamak HT-7U as a national important research facility [1]. Main parameters of HT-7U are $B_T = 3.5$ T, $R_0 = 1.75$ m, $a = 0.4$ m, elongation κ $(b/a) = 1–2$, $I_p = 1$ MA, $P_{LHCD} = 3.5–4$ MW, $P_{ICRH} = 3–4$ MW and maximum pulse length will be 1000 seconds (Figs. 14, 15). The main purpose of HT-7U is widely to investigate both the physics and technology for steady state and advanced tokamak. The physics design and the engineering design of HT-7U have been completed. R&D activities and the most of fabrication, construction and assembling works of HT-7U are under way in Russia, in workshop of ASIPP and Industry Company in China. HT-7U will be completed around 2003 year.

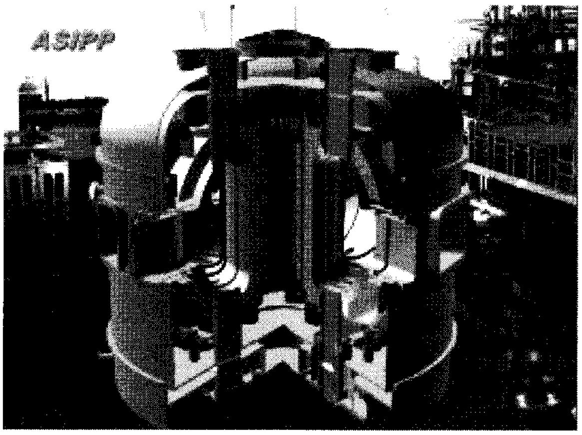

Fig. 14 HT-7U tokamak

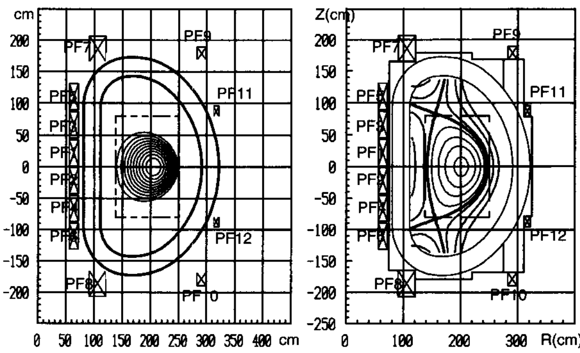

Fig. 15 Typical configuration of HT-7U

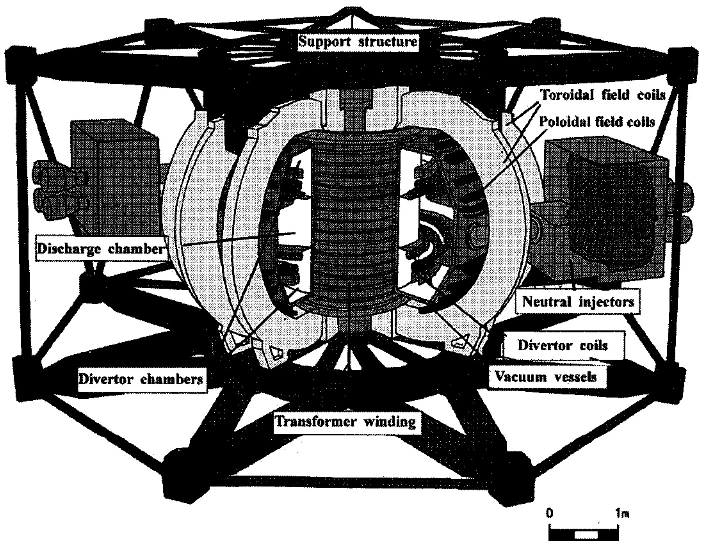

Fig. 16 HL-2A tokamak in SWIP

In SWIP HL-2A tokamak based on original ASDEX main components is under construction (Fig. 16) [9]. HL-2A project is the extension and the continuation of HL-1M tokamak and its main mission is obtaining experiences on divetor plasma and elongated plasma control. The main parameters of HL-2A are $B_T = 2.8$ T, $R_0 = 1.64$ m, $a = 0.4$ m, $\kappa(b/a) = 1{\sim}1.3$, $I_p = 0.48$ MA, $P_{LHCD} = 3$ MW, $P_{ICRH} = 3$ MW, $P_{ECRH} = 1$ MW, $P_{NBI} = 3$ MW. The construction is on schedule and the commissioning will be at the first half of next year. HL-2A will be upgraded to HL-2M in future.

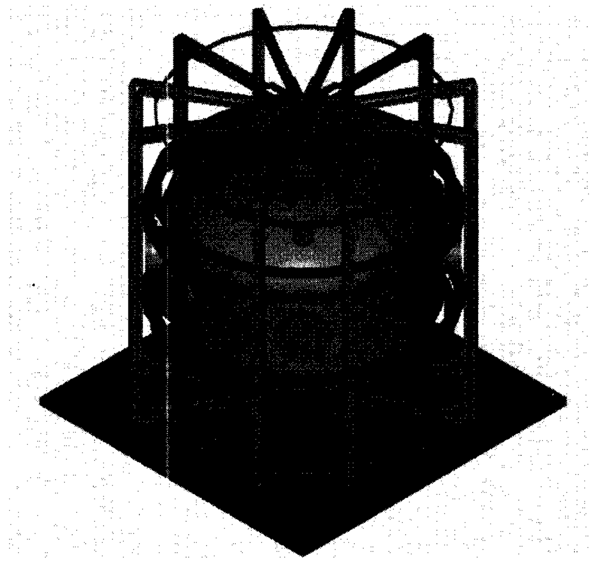

Fig. 17 Main components of SUNIS

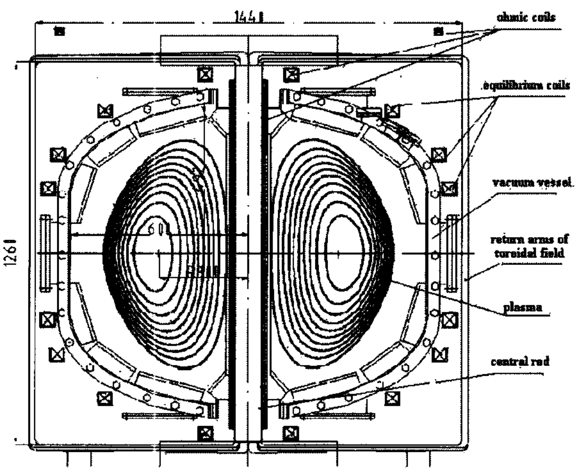

Fig. 18 Calculated magnetic surface of SUNIST

SUNIST is the university scale conceptual spherical tokamak (Fig. 17, 18) [10]. Parameters are $R_0 = 0.3$ m, $a \sim 0.23$ m, aspect ratio $A > 1.3$, $\kappa(b/a) \sim 1.6$, $B_T = 0.15$ T, $I_p = 0.05$ MA, central rod current $I_{ROD} = 0.225$ MA and flux swing ~ 0.06 Vs.

It is under construction in Qinghua University and will be completed at first half of 2002.

Possible Future Plane

At first Chinese magnetic confinement fusion community will joint together to promote to participate in the ITER program if ITER will be constructed finally. Secondly a hybrid test tokamak reactor may be proposed around 10 years late if HL-2A and HT-7U are full success. Related research activities are under way.

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