Research Program of Spherical Tokamak in China

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In past thirty years, Chinese fusion research activities have been concentrated in tokamak configuration machine until 1999, such as CT-6, HT-6B and M, HL-1 and M, KT-5, and HT-7 with superconducting toroidal field magnet. There are two tokamak programs that just be developing, HT-7U superconducting tokamak [1] in IPPCAS aimed at steady state AT (advanced tokamak) operation, and HL-2A tokamak [2] in SWIP with the motive on reversed shear and high performance tokamak operation.

The first research program of spherical tokamak in China is supported by National Nature Science Fund, Subject Development of Tsinghua University Project and Director Fund of Institute of Physics, Chinese Academy of Science. This program has been executed from 1999 and plans to finish at the end of 2002. The research activities in first period include establishing a spherical tokamak device, named SUNIST (Sino United Spherical tokamak) located at Tsinghua University, a united laboratory and the preliminary experiments of spherical tokamak. This paper will introduce SUNIST facility (Chapter I), research project (Chapter II), status (Chapter III).

I SUNIST facility

The mission of this program is to explore the spherical torus plasma with the SUNIST spherical tokamak. SUNIST is a university scale conceptual spherical tokamak, with following parameters:

major radius	R	0.3	m
minor radius	a	~ 0.23	m
aspect ratio	A	>1.3	
elongation	κ	~1.6	
toroidal field at R_0	B_{T0}	~0.15	T
plasma current	I_P	0.05	MA
central rod current	I_{ROD}	0.225	MA
normalised current	Ip/(aBo)	1.45	
flux swing	ΔΦ	0.06	Vs

SUNIST device [fig.1] consists of vacuum vessel, toroidal and poloidal coils, structure. peripheral systems include vacuum, pulse power supply, diagnostics, control and data acquisition, ECR wave.

Vacuum vessel: 304 stainless steel vacuum vessel consists of a 0.5 m tall, 1.2 m diameter cylinder capped on each end with elliptical domes with 6 mm thickness. The center post has a radius of 0.065 m with 1mm thickness, and there is a maximum of 1 m of vertical clearance between the domes. A viton cross seal ring, between two half outer shells, and central post, provides the electrical break along toroidal and poloidal direction (fig,2). We suppose that would be helpful for saving the vs of ohmic solenoid and plan to check the effect of vessel eddy current to plasma discharge. Although we have taken a test (fig.3) for sealing quality of cross seal ring and seal technology in 2000, but that is still a key issue for us.

Ohmic field coils The ohmic solenoid is the heart of ohmic system, 130mm of outer diameter, 1176mm of height. This solenoid is a double wrap of oxygenfree copper windings with 224 turns rounded on central rod of toroidal field directly. An ohmic trim coil set is constructed to pull the returning flux from the ohmic solenoid out of the plasma region. The total 236 turns is connected in series. The design flux is 80 mVs.

Toroidal Field Coils The 24 turns, consisted of two layers in central rod and 12 sets on return arms, are connected in series. The knock-down TF can be divided two‶L″ type part, central rod, lower return arms and upper, outer return arms. Movable connections are located at top of central rod an upper return arms, lower and outer return arms. Its inductance is 0.548 mH. Its time constant is 92.2 ms.

Equilibrium Field Coils There are 3 pairs of coils to hold plasma at its equilibrium position. The issues in coil system (fig.4) are toroidal field coil connection and ohmic solenoid with high current density, so high stress and thermal load.

Vacuum system A 1000 l/s turbomolecular pump is arranged as the main pump. The base pressure is 1×10^{-5} Pa. The working gas can be injected into the vacuum vessel with a piezoelectric leak valve continuously or in pulsed regime. A quadrupole mass-spectrometer is installed for gas analyses and leakage detection. The conditioning methods will include baking the vessel to ~ 150 ^{0}C, glowing discharge with helium or hydrogen, in-situ deposition of silicon film and training discharge.

Wave system A microwave pulse magnetron source is prepared for preionization, plasma current ramp up and current drive at first phase of SUNIST program. This source is with 2.45 GHz of frequency, 100 kW of pulse power and 30 ms of pulse width.

Power supplies

system	I_{MAX} kA	V_{MAX} V	L µH/R mΩ	energy
toroidal	10	200	521/5.3	2.56F/400V
ohmic	±13	4700	532/18.3	3.4mF/5kV+10.3mF/500V,
equilibrium	2	200	697/15.5	0.1F/250V
microwave	23A	25000	< 30ms	125µF/25kV

II Research projects in start phase in SUNIST

Electron cyclotron wave current startup Since plasma current startup is a difficult task in a spherical tokamak due to the condition of ohmic transformer and vessel's eddy. And that would be concerned some important plasma performance, for example, additional heating at start phase could improve the globe behaviors of plasma in flat top stage in START [3] and double tear mode might be the reason to limit the ramp up rate of plasma in PEGASUS [4]. The current startup is the first research topic in this device.

In the CT-6B tokamak in the Institute of Physics, Chinese Academy of Sciences, electron cyclotron wave current startup has been widely studied and this startup scenario was demonstrated to be effective [5]. As the first step, a 2.45 GHz microwave source will be used in the experiment. A novel current startup concept, the electrode-assisted electron cyclotron wave current startup, has been proposed and demonstrated in the CT-6B [6]. A strong toroidal field and a weak vertical field are applied in the experiment. A discharge is triggered between two electrodes located at top and button of the vacuum chamber. The discharge current flows along the helical magnetic force lines and is magnified in the toroidal direction.

The special structure, toroidal break, is not only useful for saving Vs which is our original purpose, but also to provide a method to explore the effect of eddy and its distribution of vacuum vessel on plasma behaviors. Finally this assembling structure of central component would allow us to change a central solenoid with big size when we want to point our research to A~1.6 plasma.

Microinstabilities and plasma turbulence Few results on the topic in spherical tokamaks are reported so far. This important research issue is also the continuation of experiment work performed in the CT-6B [7]. It includes drift wave strong turbulence, coherent structures, plasma rotation, parallel flow instability, transport barrier, H-like mode. Electrostatic probes and optical method, and advanced data analytic methods (for example, wavelet analyses) will be used in the research.

III Status

Vacuum vessel's machining procedure is going to complete and inspective operation will begin in early August. Magnet components will complete in later August. We plan to start general assembling at the end of third quarter of this year and test operation at end of 2001.

The microwave generator is ready, its power supply is going to reconstruct from an ECRF gyrotron power supply in CT-6B tokamak. Toroidal field power supply is finished and used for large current connector test. Poloidal field power supply will be installed in-situ with CT-6B's components in SUNIST laboratory in the 3rd quarter of this year.

The soft X-ray array with 28 channels is going to finish. H_α array, spectroscopy diagnostics and electrostatic probes of CT-6B will be move to SUNIST. Eletromagnetic diagnostics is just developing with the cooperation of Southwestern Institute of Physics. A set of data acquisition system with 32 channels and higher than 1 MHz bandwidth will be use for SUNIST in start pha se. PC and relative modular and software for discharge control are close to finish. Plasma experiment of SUNIST will be start in 2002.

Reference

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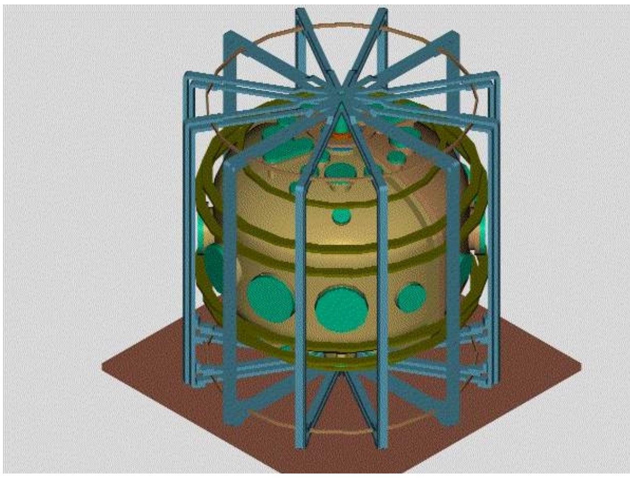

Fig.1 SUNIST spherical tokamak

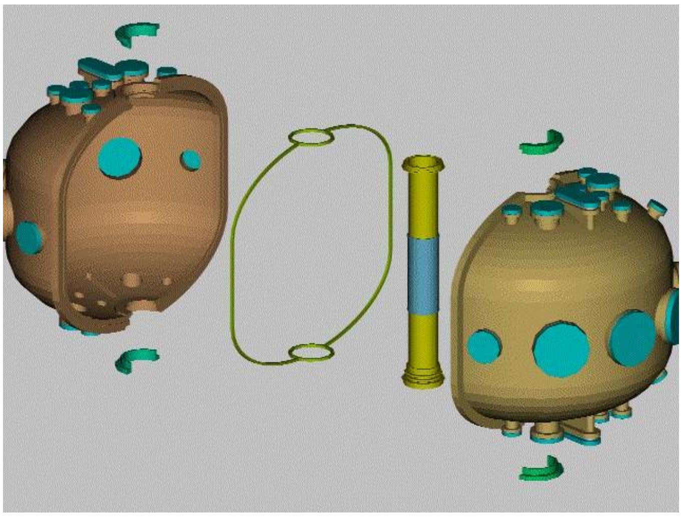

Fig. 2 vacuum vessel and insulating break

Fig.3 test for cross seal of vessel

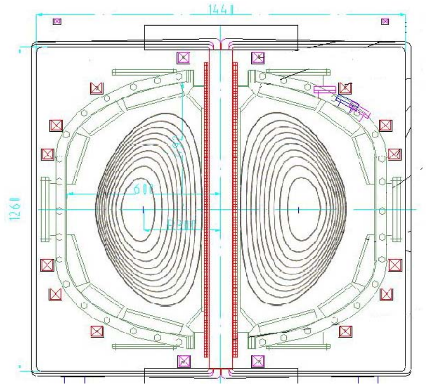

Fig.4 SUNIST cross section