2.7 Recent progress on the HL-2M design

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Abstract：The recent progress on HL-2M design is introduced in this report. The engineering design for vacuum vessel, in-vessel components, poloidal field coil system and support structure is presented, the preliminary assembly scheme of HL-2M machine is put forward.

Key words：HL-2M；Vacuum vessel；In-vessel component；Poloidal field coil system；Support structure

The design of HL-2M is based on the physical objectives of elongated plasma configuration, advanced divertor and high parameter plasma. In order to get I_P of 1.2 MA, the poloidal coils are arranged outside the toroidal field（TF）coils. The engineering design includes vacuum vessel（VV）, in-vessel components, poloidal field（PF）coil system, support structure system and assembly technology etc. All design activities are combined with the general assembly scheme and the manufacture technology. The detail design and optimization of main subsystems of device are underway. This report presents the recent progress of these subsystems design and considerations of their assembly.

1 Vacuum vessel and inner components

The VV is a fully welded torus with double wall structure. The design of the torus is to meet the demands of TF coils assembly and includes two parts, one is big which consists of 14 standard sectors, the other one is small which consists of special sectors. The VV is shown in Fig.1（a）. All horizontal ports, vertical ports, oblique ports are considered for the requirements of engineering structure, diagnostic and heating experiment. Some modifications on VV such as the ribs number, gravity supports position and so on have been done, but the general dimension has not been changed.

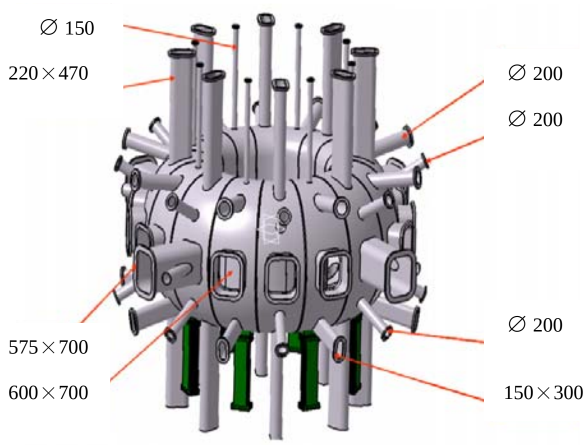
In order to increase the toroidal resistance of the vessel torus, Inconel 625 has been chosen as the vessel material because of its good mechanical properties and high resistance ratio, SS316L will be chosen for port tubes and flanges.

8 gravity supports [Fig.1（b）] are arranged toroidally under the vessel bottom, and attached to the lower spoke wheel of the device. Each support has 15 steel plates with thickness 12 mm. This structure can make the vessel move along radial direction during heat expansion during baking-up or heat operation.

Components such as first wall, divertor, passive stabilization plate（PS）, active control coil，diagnostic cryopump are arranged in vessel, as shown in Fig.2.

Divertor is one of the most important in-vessel component. It consists of outer target plate, inner inclined target plates, domes and baffle plates in the bottom space of the VV. The divertor is separated into 16 segments（22.5 sector）respectively in toroidal direction to allow install/remove within the limitation space. The materials used for the divertor are mostly SS-316L for the structure and cooling water folds, CuCrZr alloy for heat sink and coolant tubes, and graphite for the plasma facing material. Individual cooling system of each sector is connected to cooling water fold through removable fitting. The conceptual design of PSL has bee finished.

（a）



（b）

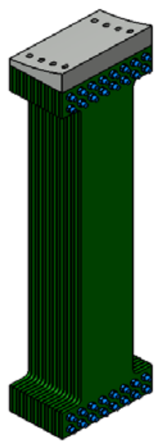


Fig.1. Vacuum vessel, in-vessel components and support.
（a）Vessel and ports；（b）Gravity support.

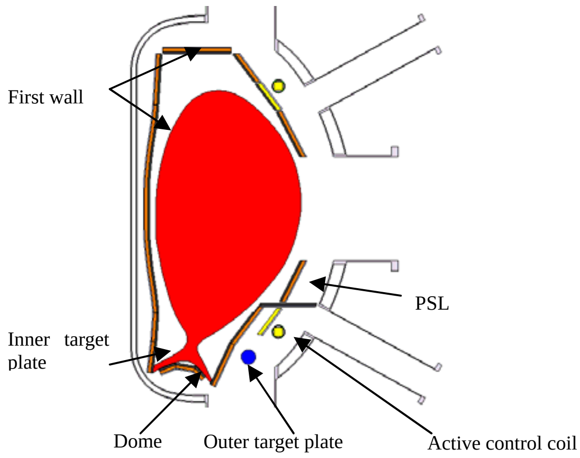


Fig.2. Cross section of inner components of VV.

2 Poloidal field coil system

Integrated with the consideration of space location, magnetic force, support, feeders, cooling water inlet and outlet etc., the parameter of PF coils have been optimized, and the shape of coils cross-section, the total number of coil windings and the number of windings of one coil part（pancake or cylinder）, the total maximum length of coil part have been adjusted. Table 1 gives the parameters of PF coils.

Table 1 PF coils parameters

	R/mm	*Z*/mm	*H*/mm	*W*/mm
CS1	440	0	1628	270
CS2	440	±1388	1048	270
PF1i	1100	±2420	430	232
PF1e	1450	±2420	430	244
PF2	3050	±1750	262	402
PF3	3480	±800	260	202

PF coils will endure electromagnetic force and thermal effects during operation, the maximum stress within the conductors will be less than 110 MPa, and the bent stress in vertical direction should be less than 10 MPa. Since each coil current will get the maximum load, a complicated holding system will reduce the stress of vertically acting force and thermal radial movements.

The PF coils should be arranged as close as possible to the plasma, the high voltage and high current of PF coils produce current density up to 45MA/m^2, and the insulation shell of the coil should have high voltage stress, which is achieved by special technology. The difficult of PF manufacture lies in winding, conductor joint, insulation and vacuum pressure impregnation etc.

The material Cu with silver is used for all PF coils conductor, and the Cu-Be will be used as the feeder because of its high strength.

The turn-to-turn insulation of PF coil is 1 kV DC, and the DC breakdown voltage is higher than 50 kV. The coil located within VV will be divided into segments. The technologic problems such as high temperature insulation, thermal expansion, heat stress, vacuum seal, feeders, joints, support and assembly etc. should be considered seriously.

3 Support structure

The device support structure includes general gravity support, TF coils support, PF coils support and VV gravity support. In order to make the peripheral equipment such as diagnostic and heating system can be used again, the height between the equatorial planes to the ground is set 5.80 m, same as HL-2A and the equatorial plane to the second floor is 1.30 m.

The general gravity support of the device includes support pillars and lower spoke wheel. The support pillars are divided into two groups, one is inner group with 4 pillars and the other is outer group with 16 pillars. The outer pillars include 8 main support pillars and 8 assistant support pillars. The main pillar will be a 550 mm×550 mm concrete column, the adjustable support seats in HL-2A can be reused for good plainness of lower spoke wheel of HL-2M. The PF coils are supported by lower and upper spoke wheel in order to get good accessibility of diagnostic equipment and arrange tangential winders of vacuum vessel. The upper and lower spoke wheel are connected by only 8 vertical beams, and other load points will be supported by anticlinal beams. The support structure is shown in Fig.3.

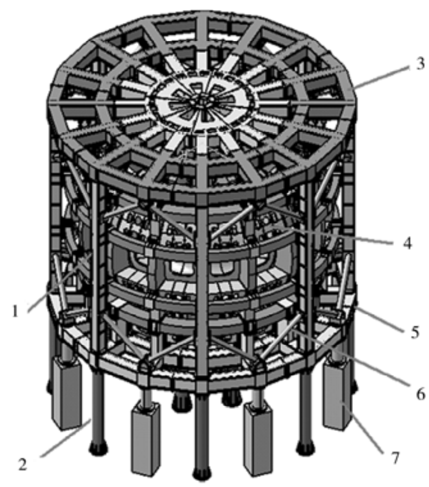


Fig.3. Support structure of HL-2M.

1——Vertical beams；2——Assistant support pillar；3——Upper spoke wheel；4——Turn-over structure；5——Lower spoke wheel；6——Anticlinal beam；7——Main support pillar.

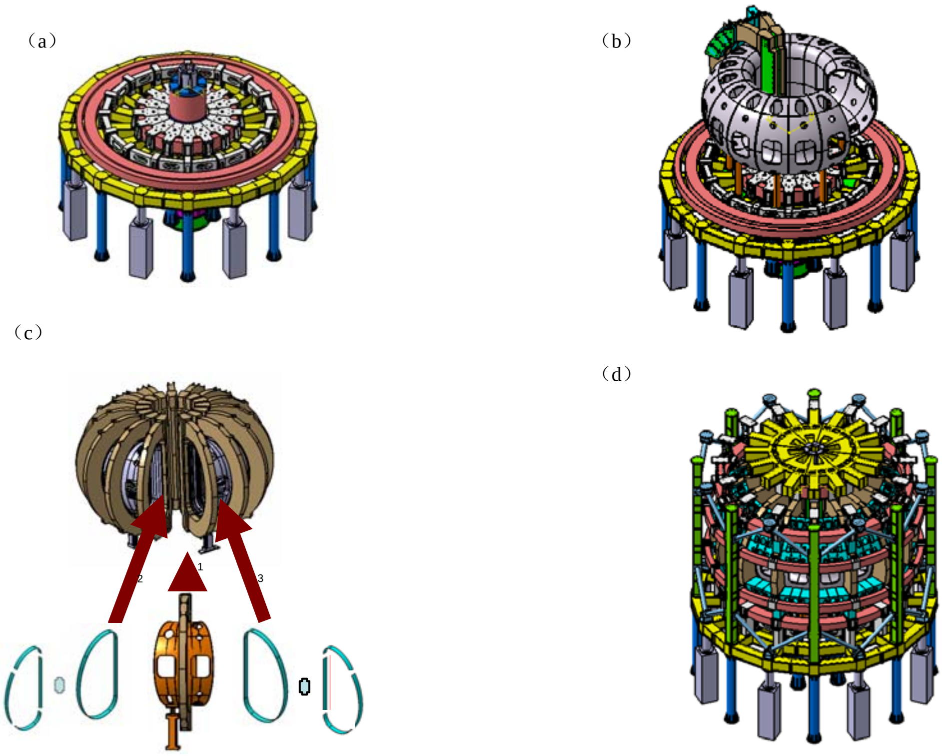


Fig.4. Typical steps of HL-2M installation.

（a）Drop down of the CS coil;（b）Installation of TFC;（c）Installation of final TF coils and non-standard vessel section;（d）Installation of up PF1 and its support.

The central solenoid（CS）is divided into 3 coils, and the support structure includes knee-and-column base, support seat and up press block.

4 Assembly scheme

Because of the structure characteristics difference between HL-2A and HL-2M, HL-2M has different assembly technological process and requirements. The total weight of HL-2A is about 450 tons, while HL-2M is nearly 500 tons, only 10% more than of HL-2A, the basement of HL-2A can be used in HL-2M. Some component weighs up to 30 tons, but the maximum capacity of HL-2A bridge crane is only 20 tons, so it must be modified, but the lifting height of bridge crane must not be changed because of the tokamak hall roof limitation.

The general assembly has many steps, Fig.4 just gives some key and typical steps. During assembly the CS coil should be drop-down to facilitate the installation of VV, Fig.4（a）.

All PF coils are located outside TF coils, and the VV is a whole welded torus. In order to facilitate the TF installation, a gap is set for the big part for the TF assembly, Fig.4（b）. After installing all TF coils, the non-standard section of VV part will be welded together with the big one by side flange, Fig.4（c）. The PF1 coil will be assembled with upper spoke wheel on a special platform and then installed to the device, Fig.4（d）, and this integrated component will determine the bridge crane lifting ability.

5 Summary

The design of VV, in-vessel components, and poloidal field coil system and support structure is going on. The manufacture process of main components will be discussed with the factory further. Inconel 625 is chosen as the material of VV body and it can increase the toroidal resistance and mechanical properties of vessel torus. The specialized personnel on ANSYS are checking the VV design. The PF coil system has been optimized, and more calculations will be carried out for different discharge scenarios, different time slices etc. New support structure has been considered based on VV body, ports, PF loads, feeders, inlets and outlets of cooling pipes. Preliminary scheme of assembly procedures is planned.

The engineering design of the main systems of tokamak machine will go on. Wider and deeper discussion with the related industry departments will continue.