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Applications and Prospects of Modularization Technology in HTR Project Starting from Primary Loop Cavity Construction

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Abstract –*Primary loop cavity is one of the key areas and major difficulties in HTR-PM project construction. In order to shorten the construction schedule and improve the construction quality, researches on modular design and construction of primary loop cavity has been carried out and the results have been applied in HTR-PM project construction, and got significant application benefit. This paper summarizes the modularization technology application research and project implementation results of primary loop cavity, and analyzes the application and prospects of modularization technology in the HTR project construction.*

I. INTRODUCTION

High temperature gas-cooled reactor pebble-bed module (HTR-PM) demonstration plant project with output around 200MWe has been listed in National Key Science and Technology Project. Many design and construction challenges exist due to the new type reactor and tight construction schedule. Primary loop cavity, as the containment that accommodate the primary loop systems, is one of the key difficulties in HTR-PM construction due to its complicated structure, large scale, high requirements for construction ,long construction period and on the critical path[1]. Advanced technology is urgently needed to be adopted to shorten its construction schedule and improve its construction quality. Modularization, as a new construction technology, has widely been paid more attention and applied among the Nuclear Power Plant, which can improve construction quality effectively, shorten construction period and reduce comprehensive cost of the project[2][3]. The HTR-PM demonstration plant adopted the modularization technology in primary loop cavity construction. The research of modularization technology has been carried out and applied which got significant application results. And so modularization technology will be applied more widely in subsequent HTR project construction.

II. ANALYSIS OF PRIMARY LOOP CAVITY CONSTRUCTION DIFFICULTY

The HTR-PM deploys two identical pebble-bed modular high temperature gas-cooled reactors of 250MW thermal power, and two reactor modules are coupled with two steam generators which are connected to one steam turbine-generator of 200MW electric power. The reactor and the steam generator, connected by a hot gas duct, are installed inside two separate concrete shielding cavities, constitute "shoulder to shoulder" in layout. Each primary loop cavity consists of reactor cavity and steam generator cavity (Fig.1). Two primary loop cavities are parallel arranged within the reactor building.

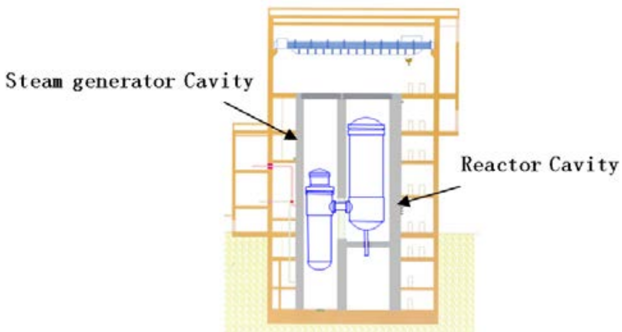

Fig.1 Section view of primary loop cavity of HTR-PM

Primary loop cavity construction of HTR-PM has the following difficulties:

(1) Huge project quantities, long construction period

Reactor cavity is a columnar cavity with a height of 32.1m and wall thickness of 2.4m. Steam generator cavity is a rectangle cavity with a height of 43.6m and wall thickness of 1.5m. Because of thick walls, dense steels, huge quantities and on the key path of project construction, primary loop cavity construction period accounts for about 34% of the total project construction period, which has a great influence on the construction period of HTR-PM.

(2) As the special system of HTR, Shield cooling water system has great difficulty in construction

In order to prevent the excessively high temperature of the cavity concrete, HTR has two shield cooling water systems (SCWS, Fig.2) installed in the wall of two cavities. The system is mainly formed by the upper and lower headers, cooling water pipes and water-cooled walls, and is a cage-like structure.

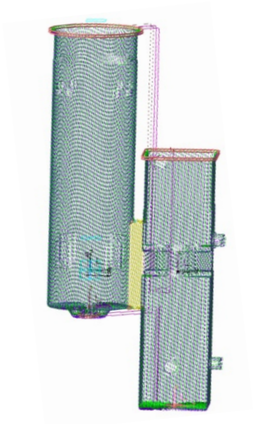

Fig.2 Graphic model of shield cooling water system

The system has the characteristics of large and densely arranged pipeline (the total length is about 24,000m, and the weight is about 80t , tube spacing only 13.7cm), close with large number of pre-embedded parts(circle or cool), complex shape(about 2,000 elbows).The technical requirements for the plumbing installation are more strict than the boiler convection tubes. This system is installed in the wall, so cross-construction is common, which causes large amount of work and difficulty.

(3) Large quantity, miscellaneous types of embedded parts and penetrations, high construction requirements

The number of pre-embedded parts is over 100 and the penetrations is over 200, involving mechanical, pipeline, electrical, instrument and ventilation, etc. With wide construction area, large project quantities and high installation requirements., especially the large weight RPV and SG supports (Fig.3) (the weight of RPV support is about 20t per one), high accuracy (the height deviation is less than 1mm, the horizontal deviation is less than 0.5mm, etc.) , which all cause the high difficulties of construction.

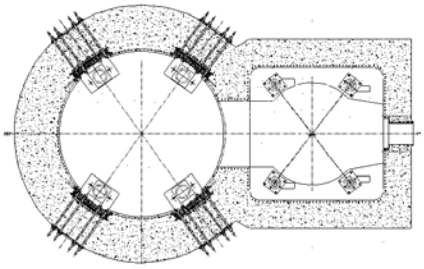

Fig.3 Diagram of main equipment support in primary loop cavity

(4) Narrow construction field and massive high-altitude operations

Reactor cavity is a cylindrical cavity of 8.76m in diameter and 32.1m in height. Steam generator cavity is a rectangle cavity measuring 7.11m×7.0m and having a height of 43.6m. Narrow construction field and massive high-altitude operations bring great challenges to the construction and safety.

III. MODULAR DESIGN OF PRIMARY LOOP CAVITY

Given these challenges mentioned above, the HTR-PM project adopted the modular construction methods, which means related components are designed and assembled into several modules, manufactured ahead in pre-fabrication field, lifted and installed in place by large crane , poured concrete after module installation, insert steel and formwork jobs completed, which shortens the construction period, reduces construction difficulty and ensures construction quality and security.

III.A. Module type

According to the characteristics of primary loop cavity, bracket module type is ultimately adopted through comparison among a number of schemes, which is based on shield cooling water system, and add-set a steel skeleton construction comprised by profile steels to support and position the pre-embedded parts such as the pipes of SCWS, the casing of throughout parts, etc, and ultimately form a mesh, cage-like structure module. The steel skeleton mainly consists of three parts: steel columns, circular rims and intermediate supports with the role respectively of module fasten and support, water pipes of SCWS fasten and the skeleton reinforcement and module installation, which will be removed after module is installed.

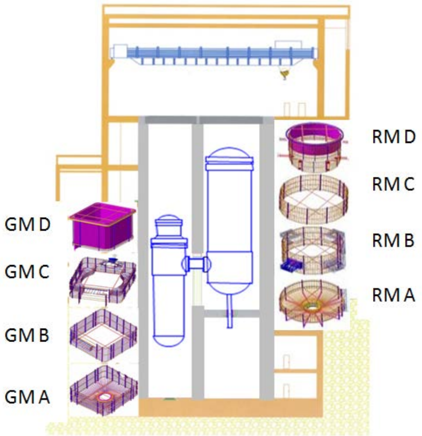

Fig.4 Diagram of modular design scheme of primary loop cavity

The advantage of the scheme is that: easy to adjust when the design changes; design changes of related process system is limited; less increased steel scaffold (only about 40t); low requirement for the lifting capacity as the small weight of module; shorter pre-fabrication time and construction schedule.

III.B. Research on modular design

The difficulty of modular design is how to reasonably divide the modules and nicely coordinate the conflict between civil construction and installation to shorten construction schedule. According to the characteristics of primary loop cavity, following principles of module division are determined:

(1) Reduce the module number. To shorten the construction schedule and reduce the connective workload between the modules, each module should be integrated more components. But the weight of each module must not exceed the capacity of the crane on site.

(2) Reduce the connective difficulty between the modules. In order to facilitate welding, the module interface are generally selected at the location where cooling water pipes shape is regular, and special parts such as support parts and throughout parts should be avoided.

(3) Merge special pre-embedded parts into sub-modules. For the large pre-embedded parts surrounded by the complex shape water pipes, the pre-embedded parts and its pipes should be integrated into a separate sub-module, then prefabricated and assembled on site in advance.

(4) Discriminatively consider the equipment supports .SG supports are merged into the modular manufactured and installed as a whole to improve the installation accuracy and efficiency. Reactor supports are designed as four sub-modules due to the large weight,. In order to reduce the module lifting weight, the removable parts of reactor supports can be dismantled first, then installed when is in place.

(5) Coordinate the civil construction and installation. The division of modules should fit to the construction stratification as much as possible, and generally consider the height of pouring surface and the length of the template, to facilitate cross-operation and schedule coordination between the construction and module installation. The module interfaces are generally set above the floor to facilitate welding operation. Ensure the welding datum plane of reactor cavity and SG cavity have the equal height as much as possible to facilitate generally control the construction schedule of two cavities.

(6) Matching with design & procurement schedule. As HTR-PM is a demonstration plant, coordination with design & procurement schedule of related systems should be considered especially in order to reduce the impact of design changes and meet the requirements of module manufacturing and project schedule.

According to the above principles, the modular division and design for primary loop cavity has been completed, the 3D-model of each module has been made up by 3D-design software CATIA. The modular design scheme are shown in Fig.4, the modular design scheme are shown in Tab.1 and Tab.2.

Tab.1 Modular design scheme of SG cavity

Module No.	Module height(elevation)/m	Module weight /t	Main components of module
GMA	7.5 (-15.5~-8.0)	10	Module steel frame(16 columns); Cooling water pipe(156, 2 lower headers)

GMB	10.3 (-11.0~-0.7)	8.1	Module steel frame(8 columns); Cooling water pipe(156 in the vertical, 2 transition headers)
GMC	6.7 (-1.7~5.0)	52.7	Module steel frame(18 columns, corbels supporting structure); Cooling water pipe(156); SG support(4 groups); Rails(4); Corbels steel cladding(2); Corbels rebar
GMD	10.65 (4.15~14.8)	38.5	Module steel frame(18 columns); Cooling water pipe(156 in the vertical, 2 upper headers and 2 transition headers); Steel cladding (8.5m high)

Tab.2 Modular design scheme of reactor cavity

Module No.	Module height(elevation)/m	Module weight /t	main components of module
RMA	10.5 (-5.5~5.0)	39	Module steel frame(6 columns); Cooling water pipe(160 in the vertical, 2 lower headers and 2 transition headers); The box at the bottom of reactor cavity
RMB	8.85 (4.15~13.0)	14.4	Module steel frame(8 columns);Cooling water pipe(160, 2 transition headers); Ring pre-embedded parts of the decay heat removal system(1.25m high)
RMC	8.5 (13.0~21.5)	21	Module steel frame(8 columns); Cooling water pipe(160);Steel cladding (2m high)
RMD	6.5 (21.5~28.0)	35	Module steel frame(8 columns); Cooling water pipe(160 in the vertical, 2 upper headers); Steel cladding(6.6m high)

III.C. Design and calculation verification of module support structure

Sufficient strength of module support structure is needed to ensure the stability of module manufacturing, lifting, installation, and also facilitate construction. For the following three typical conditions, analysis and verification of support module structure's design and mechanical properties has been conducted with the finite element analysis software.

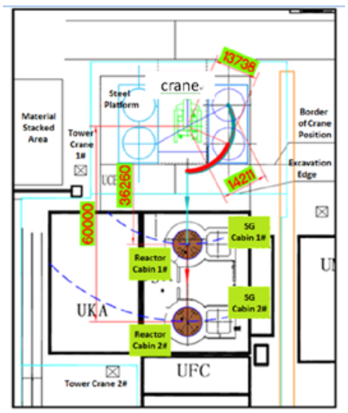

Fig.5 Diagram of construction field layout plan

(1) Condition 1: pre-fabricated condition. All columns are fixed on the same platform, which is equivalent to impose a fixed-end constraint at the bottom of the connection point, the weight of water in this segment module for hydraulic pressure test of the pipes of SCWS should be considered. Internal stress and steel structure external deformation should be inspected.

(2) Condition 2: lifting condition. Main columns are fixed on crane, which is equivalent to impose the fixed-end constraint at the upper end of the connection point. Move the module slowly, its force can be nearly equivalent to static load, internal stress and steel structure external deformation should be inspected.

(3) Condition 3: accident condition. Sub-module is a permanent structure installed in the concrete. The concrete temperature is 20℃ during normal operation and can reach up to 100℃ during accident condition, internal stress and steel structure external deformation should be inspected.

For condition 1 & 2, the calculation results show that, the maximum internal stress and external deformation mostly appeared at the header or support cantilever beam, weld of tic-tac holder and column, weld of column and u-steel, the areas that have large change in shape around SG cavity corbels, etc, which are strengthened in design such as increasing the number of cantilever beam, replacing u-steel cantilever beam with double t-steel cantilever beam, choosing larger specification to enhance the flexural capacity of steel. The inspection results show that module support structure can meet the strength requirements.

For condition 3, because of small changes in temperature (80℃), the support structure module thermal stress and thermal deformation are very small which will not form negative impact to the concrete. The calculation results proved that the design of module support structure can meet the requirements.

IV. PRE-FABRICATION AND INSTALLATION OF MODULES

Primary loop cavity module will be pre-fabricated on site with two steel platforms, each size is 12m×24m, and can pre-fabricate one reactor cavity module and one SG cavity module simultaneously. The steel platforms and cranes can be set at the electric building because of the later built building,. The specific layout is shown in Fig.5.

Each module pre-fabrication on the steel platforms completed, will be directly lifted it to the installation position by a 400t crawler-type crane, which can save the transportation work. Fig.6 shows pre-fabrication and installation of an example module named RMA module. Module installation and construction of primary loop cavity are cross-conducted. In principle, module installation should be first, then banding steel and pouring concrete.

Fig.6 Pre-fabrication and installation of RMA module

Fig.7 Diagram of HTR-PM site

V. APPLICATION EFFECT ANALYSIS

The modular design scheme of primary loop cavity has been applied in HTR-PM project construction. Two GMA modules were successfully installed into the place on April 14, 2013. Up to now, pre-fabrication and installation of 12 modules (16 modules total) have been completed(Fig.7) which improved the construction quality and safety, shorten the project construction period effectively by 2 months at least. Application effect is significant.

VI. APPLICATION PROSPECTS ANALYSIS OF MODULARIZATION TECHNOLOGY IN HTR PROJECT

Modular design is the prerequisite of modular construction. Modular construction requires closer cooperation on all aspects including engineering, procurement, construction (EPC). HTR is a new type of reactors, independently developed by China, and HTR project using Chinergy Co., LTD. as the EPC general contractor for nuclear island construction, which provides the favorable technical conditions and management support for widely application of modularization in HTR project construction.

Primary loop cavity module is the first module introduced to engineering applications in HTR-PM. Its successful implementation has not only proved the great benefits of modularization technology applications, but also accumulated valuable experiences for HTR. On this basis, we have carried out a lot of research and development works for widely promoting the use of modularization technology in HTR project and achieved significant results:

(1) Have proposed and mastered a whole set of criteria and method of HTR modular design, including HTR Modular Risk Assessment Methods, Modular Area Selection Methods, Modules Classification and Division Method, etc.

(2) Have carried out the research and test on basic performance, seismic performance and fire resistance for steel plate concrete structure composite wall and semi-steel plate concrete floor structure, and formed Design Guide.

(3) Have built a special IT design platform that can meet the requirements of modular design.

(4) Have determined candidate module areas that fit modular design in HTR NI, and further identified key module areas through analysis and evaluation.

(5) Have completed modular design scheme and benefit evaluation of typical module areas including helium purification system, steel & concrete structure cavities, etc.

These achievements have laid an important foundation for widely applying modularization technology in HTR. Subsequent commercial HTR will apply modularization technology with larger scale. It can be forecasted that effect of the wide application of modularization technology will be more significant.

VII. CONCLUSIONS

Applied modular construction technique in primary loop cavity of HTR-PM is the first attempt of modularization technology application in HTR project, which shorten the construction schedule and improve the construction quality, the application effect was significant and accumulated a lot of valuable application experiences. Promotional application of modularization technology in HTR project has good technical and management foundation. We will expand the application range of modularization technology in subsequent 600MW HTR commercial NPP to shorten construction period, improve construction quality and build HTR faster and better.

VIII. ACKNOWLEDGEMENT

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