HTGR Metallic Reactor Internals Core Shell Cutting & Machining Anti-deformation Technique Study

Xing Huiping, Xue Song
Shanghai No.1 Machine Tools Works Co., Ltd.
No.185 Yitian Road, Pudong New District, Shanghai, China
phone: +86-021-38221070, xinghp@shanghai-electric.com

Abstract – The reactor shell assembly of HTGR nuclear power station demonstration project metallic reactor internals is key components of reactor, remains with high-precision large component with large-sized thin-walled straight cylinder-shaped structure, and is the first manufacture in China. As compared with other reactor shell, it has a larger ID (Φ5360mm), a longer length (19000mm), a smaller wall thickness (40mm) and a higher precision requirement. During the process of manufacture, the deformation due to cutting & machining will directly affect the final result of manufacture, the control of structural deformation and cutting deformation shall be throughout total manufacture process of such assembly. To realize the control of entire core shell assembly geometry, the key is to innovate and make breakthroughs on anti-deformation technique and then provide reliable technological foundations for the manufacture of HTGR metallic reactor internals.

I. INTRODUCTION

The core shell assembly of metallic reactor internals for HTGR nuclear power plant demonstration project is a key component of reactor. The whole core shell assembly is a large-sized, thin-walled and straight-cylindrical structure. The overall length of core shell is up to around 20000mm, its inside diameter (ID) up to Φ5360mm, and its major structure is composed of 40mm thick 12Cr2Mo1R plates. During manufacturing due to very easily deforming of shell, the non-conformance to design requirements could occur.

The machining precision of core shell assembly is much higher. Among which the critical requirements are: the flatness of lower main support surface ≤ 0.20mm; the flatness of upper end surface ≤ 0.20mm; the parallelism of upper end surface and lower main support surface ≤ 1.00mm; the roundness of shell’s inside wall ≤10.0mm; the roundness of shell’s outside wall ≤10.0mm, etc.

Fig. 1: Core Shell Structure Diagram
II. THE BASIC REQUIREMENTS FOR DEFORMATION PREVENTION DURING MANUFACTURING PROCESS

The cutting of core shell assembly shall meet the design requirements of metallic reactor internals and core shell assembly.

The basic requirements for anti-deformation during machining of core shell shall be: predictable and controllable. Only probably happened deformation during manufacturing can be predicted, program can be established beforehand to minimize the potential deformation, the deformation which is not predicted will not happen. Only the deformation is controllable, after deformation the final dimension can meet design requirements through subsequent machining or correction.

III. TECHNICAL STUDY ON ANTI-DEFORMATION DURING MANUFACTURING

Through the comprehensive consideration of special elements such as design requirements, structural features, actual factors, manufacturing flow of core shell assembly, 2 types of deformation will occur during manufacturing of the whole core shell: the deformation at cutting position and that at non-cutting position.

The controlling method for structural deformation also can be separated into two types: through pretension to keep its original shape, such that the deformation of workpiece will not occur after its cutting; through pretension to change its original shape to expected shape, to keep changed shape after its cutting.

Due to the large size of whole core shell, in order to realize dimensional control of core shell assembly, the program of machining in sections, welding into composition will be adopted at the time of manufacturing.

III.A. Basic program of machining in sections, welding into composition

As per the structure and shape of each part of core shell, the core shell separates into 8 sections that is upper flange section, shell ring section-A, shell ring section-B, shell ring section-C, shell ring section-D, shell ring section-E, shell ring section-F, and lower core shell-3, then by welding of circumferential welds the whole core shell is constituted.

Among these parts, the upper flange section is made of forging, 6 shell sections that is shell ring section-A, shell ring section-B, shell ring section-C, shell ring section-D, shell ring section-E, shell ring section-F is rolled and welded by 40mm thick-wall plates, the lower core shell-3 is welded by rolled lower thickening section and base.

After 8 pieces of 1/8 structure of core shell finish manufacturing individually, 1/4 assembly is constituted by welding of 2 pieces of 1/8 structure. And welding composition method is as follows:

The welding of upper flange section and shell ring section-A constitutes upper core shell-1;
The welding of shell ring section-B and shell ring section-C constitutes upper core shell-2;
The welding of shell ring section-D and shell ring section-E constitutes lower core shell-1;
The welding of shell ring section-F and lower core shell-3 constitutes lower core shell-2;

After 4 pieces of 1/4 assembly finish welding, and after corresponding machining, 1/2 assembly is constituted by welding of 2 pieces of 1/4 structure:

The welding of upper core shell-1 and upper core shell-2 constitutes upper core shell;
The welding of lower core shell-1 and lower core shell-2 constitutes lower core shell;

After the welding of upper core shell and lower core shell is finished, machine the last welding chamfer separately, then construct the last circumferential weld, connect upper core shell and lower core shell, finish the machining of whole core shell.

The program of machining in sections, welding into composition as shown in figure 2:

![Fig. 2: The program of machining in sections.](image-url)
III.B. Anti-deformation controlling at machining in sections, welding into composition

As per different manufacturing stage, it separates into individual 1/8 ring section controlling, 1/4 assembly ring section controlling, 1/2 assembly ring section controlling, integral controlling; on the basis of sectional controlling, finally ensure the manufacturing precision of integral assembly meets design requirements.

When the shell is in a state of 1/8 ring section, since upper flange section is a approximate 200mm thick forging, major structure of lower core shell-3 is a welded structure, integral stiffness of both parts is relatively strong, for anti-deformation pay special attention to the middle parts that is 6 shells rolled by 40mm steel plates.

The shells A to F are 6 shells with a Φ5360mm inside diameter, a 40mm thick wall, a 2490-2930mm height. It is very easy to be deformed due to thin wall thickness, and big diameter.

➢ The control scheme to single-segment shell deformation is:

When edge rolling each segment of shell, the shell diameter tolerance is required to be ±3mm and the shell cylindricity is required to be 6mm. During edge rolling, inner stiffeners will be used to true up and keep the shell shape, after having finished the shell welding, the measurement of shell OD dimension and cylindricity will be taken to judge if the requirements are met. The control of single-segment shell dimensions would allow to the control of the whole core shell dimensions to be assured when subsequent machining is performed.

➢ The control scheme to 1/4 assembly shell deformation:

After the machining of 8 segments of core shell has been separately finished, the welding of 1/4 barrel assembly will be performed. After the welding has been finished, the antideformation control to 1/4 barrel assembly will be required. The shell outline dimensions are kept mainly through the shell inner stiffeners, and whether postweld requirements are met or not shall be judged mainly through postweld shell shape measurement.

To realize the control to final dimensions, the dimensional measurement when shell is at 1/4 segment stage is particularly important. The measuring scheme is performing the point-taking angularly equidistributed at different elevations of shell assembly and making a measurement with the shell shape by means of 3D laser measurement. After measurement, the data will be subject to fitting and analysing to judge if various sections of shell assemblies meet the requirements, only after the requirements have been met can the next step’s machining proceed with.

For example, the Upper Core Shell-2 Structure Diagram is as shown in Fig. 3; The postmeasuring data is as shown in Table 1;

Fig. 3: Upper Core Shell-2 Structure Diagram

Table 1: The postmeasuring data of Upper Core Shell-2

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be made with the shells to determine post-shell-welding shape to control the shape of shells.

The control scheme to final core shell welding:

After separately finishing the machining of upper core shell and lower core shell, next step is performing the core shell’s last girth joint welding to complete the whole core shell’s final machining. When welding the last welded joint, the shell outline is maintained through the stiffening of inner stiffeners to shell, and alignment and setting are made through laser tracker to assure the shells’ whole dimensions.

After finishing final welding, a 3D photogrammetric measurement will be made with core shell barrel’s whole dimensions to acquire the whole barrel’s final outline.

The maintenance of the whole outline of barrel is realized through the process of the barrel from 1/8 segment, 1/4 assembly, 1/2 assembly to the accomplishment of final shells welding and by means of in-process antideformation control to shells at every step.

### III.C. The control to deformation during the cutting of various segments of core shell

The requirements when various segments or assemblies are machined are: the length of single-segment section is about 2,500~3,000mm, the ID is Φ5,360±3.00mm, the cylindricity is ≤6.00mm; the length of 1/4 assembly or segment is about 4,500~5,400mm, the ID is Φ5,360±3.00mm, the cylindricity is ≤8.00mm; the length of 1/2 assembly is about 9,864~10,200mm, the ID is Φ5,360±3.00mm, the cylindricity is ≤10.00mm.

The shells cutting covers the machining of different positions and shapes like weld grooves, IDs, ODs, outer edges, inner planes, holes, recesses, etc including the use of multiple machining methods like turning, milling, drilling, boring, tapping, etc to machine various segments of shells; due to temperature changes of objects being cut and internal stress changes of material, the deformation would be brought on.

To assure the control to the core shell assemblies’ dimensions during cutting, the inner stiffeners stiffening scheme shall be adopted while various segments or assemblies are being machined.

When various segments are being machined, the shells are internally stiffened by using appropriately structured inner stiffener tooling and using appropriate technique and at appropriate locations to make desired shape fixed. Meanwhile for each step’s technique and requirements, concrete operating steps and technical parameters have been provided for; and for the possible problems during the process, many modification schemes have been preestablished and prepared to realize the control to dimensions during the process of machining.

After the edge rolled barrel has achieved ID dimension requirement and shape and position tolerance requirements, according to intervals of 1,500~2,500mm, several inner stiffener toolings will be mounted inside the shells. The inner stiffener tooling close to welding grooves location is required to alter its roundness (just elastic deformation) to have the location close to welding grooves achieve technological roundness requirement, then we may proceed with the machining of welding grooves; for the other inner stiffeners’ mounting, the requirements to be achieved are: reinforce the stiffness of segments without making segments produce plastic deformation such that during the process of fabrication the segment will not produce any irreversible plastic deformation resulting from movement, turnover and local external force.

On the basis of reinforcing the barrel segments’ stiffness by using inner stiffeners, when cutting, many methods are adopted like layered cutting where each removal is specified, static aging, wet or dry machining; decrease the cuttee’ temperature buildup resulting from the cutting and gradually release and balance the material’s internal stress change resulting from the removal of material, and effectively control the final shape of cuttee.

### IV. SUMMARIZATION

For the past pressurized water reactors and other reactors shells’ dimensions, due to having a shorter overall length (9,000mm), a smaller ID (Φ3,400mm), a bigger shell wall thickness(50mm), and a relatively lower accuracy requirement, ID dimension band being ≤12.90mm, and roundness being ≤10mm, therefore machining deformations are relatively easier to be controlled.

AS compared with the past pressurized water reactors and other reactors shells’ dimensions, the length of metallic reactor internals core shell reaches about 20,000mm, ID reaches Φ5,360, having a smaller shell wall thickness (40mm), and a relatively higher accuracy requirement; for undeclared dimension tolerance band, the Class IT12 requirements in the National Standard GB/T1804-2000 shall apply, and for undeclared shape and location tolerance the Class 11 requirements in the National Standard GB/T1184-1996 shall apply, the roundness is ≤10mm, comprehensive error is relatively more difficult to control.

To achieve overall metallic reactor internals core shell assemblies design requirements, the process of manufacture has adopted the methods like
segmented machining and girth joint splicing and for each segment of shell we adopt inner stiffener stiffening scheme to perform dimensional control, to permit both making best use of generic and specific equipment of our Company and turning our Company’s precision machining and manufacturing capacity to advantage, to finally enable to realize the production and manufacture of core shell assemblies according to design requirements.