

Study on Assembly of TF Coil and Vacuum Vessel for Fusion DEMO^{*)}

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ITER is in the integration phase and a fusion DEMO is being designed conceptually. The size of the DEMO will be around 1.5 time larger than the ITER and the weight will be about three times larger than the ITER. The TF coil and the vacuum vessel of the DEMO will become very heavy and extremely large. Although the central support structure will be used in the ITER for the assembly of TF coils and vacuum vessels, the central cylinder concept is proposed in this study to avoid the huge concentrated load at the center of the device floor during assembly. In addition, the welding joint between the vacuum vessels is discussed under the limited conditions supposed on the DEMO. Since the vacuum vessel will become the nuclear boundary, all weld lines will be expected to be examined by ultrasonic testing and/or radiographic testing to ensure the soundness of the welds.

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1. Introduction

ITER project has entered in the assembly phase in July 2020. 19 TF coils will be fabricated including one extra coil. Several TF coils have been constructed by Europe and Japan and transferred to ITER site. 9 Vacuum vessel (VV) sectors are planned to be manufactured, and the first VV sector was fabricated by Korea and arrived at ITER site in September 2020. These components are very heavy and large structures. The weight of one TF coil is about 310 tons and one VV sector is about 500 tons. In the ITER web site [1, 2], a lot of photos and videos are uploaded, and one can understand the construction process and the present status easily. To assemble the TF coils and VVs, a large-scale ceiling crane with the capacity of 1,250 tons was installed in the assembly hall in the ITER site.

When the DEMO is considered, the size will be almost 1.5 times larger than ITER. Of course, it depends on the fusion power. Because of the limitation of the heat load of the diverter, 1.5 to 2.0 GW class DEMO is considering in Japan [3]. If the size becomes 1.5 times, the volume will become 3.375 times and the weight will become 3.3 times if the average density is almost the same. So, it is expected that the DEMO TF coil weight will become around 1,000 tons and the VV sector will become over 1,600 tons. These components are very difficult to fabricate and handle. The possible assembly process of the TF coils and the VV of the fusion DEMO will be investigated based on the ITER project, and a new assembly concept for the fusion DEMO

will be proposed and discussed in this study. In addition, the welding of the VV sectors is discussed, for the VV will be a nuclear boundary and all weld lines must be examined by a volume inspection process. Since the double wall structure is planned for the VV, the welding joint must be designed considering the assembly process. One weld joint will be presented, and the key issues will be discussed.

2. Assembly Scenario of TF Coil and Vacuum Vessel Sector

The ITER is a world's largest plasma device and designed to produce Deuterium - Tritium (D-T) reaction. The schematic view of ITER is shown in Fig. 1. It has 18 TF coils, 6 PF coils and 6 CS modules. The high density and high temperature plasma will be created in the VV which consists of 9 sectors. The Japan's fusion DEMO will have 16 TF coils, 6 PF coils and 6 CS modules [3].

The video in the ITER web site illustrates the assembly process of the TF coils and the VV sectors. Two TF coils and one VV sector including the thermal shield (TS) will be integrated to one combined component, and the component will be installed in the device pit.

After the installation of the lower cryostat, a central support structure will be built on the floor slab of the device pit. One scene from the ITER video is shown in Fig. 2. The central support structure can be seen under the beams. The combined component will be hung on the beam with two sets of a hanging equipment, moved to the set position and lowered vertically into the device pit.

An image of the load support of the ITER is shown in Fig. 3. The weight of two TF coils is about 620 tons (a),

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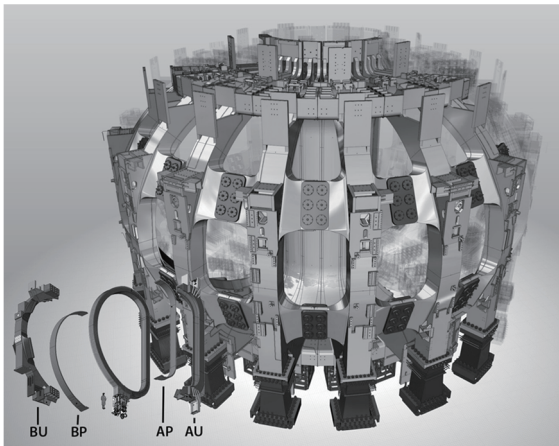


Fig. 1 Illustration of cryogenic component of ITER [1].



Fig. 2 Assembly of TF coils and VVs of ITER. Space for the last component is open [1].

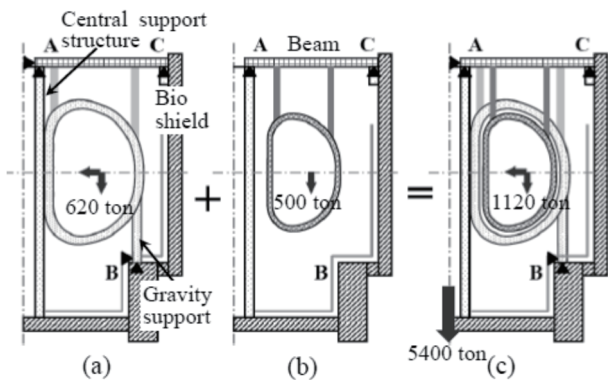


Fig. 3 Loads of TF coil and VV sector. (a) Load support of TF coil. (b) Load support of VV sector. (c) Load support of combined component of ITER.

and if the gravity supports touches the TF coils, there will be a centripetal force to the central support structure. This work seems to be a very sensitive task. The VV sector is hung on the same beam as the TF coils. The weight of the VV sector is about 500 tons (b). Supposing that the gravity center of the combined component is at the center of the beam, the central support structure will support half of the total weight of the combined components, the beams

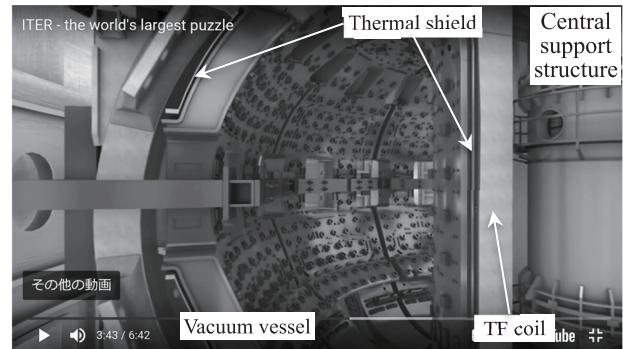


Fig. 4 Inside of VV structure of ITER. VVs are surrounded by thermal shield and TF coils [1].

and other devices and jigs. If the total weight supported by one beam is about 1,200 tons, the total load supported by the central support structure will become about 5,400 tons, which is a concentrated load to the floor slab (c). The floor slab must endure this concentrated huge load and it requires the strong underfloor structure. And this huge load exists only during the assembly period. When the fusion DEMO is imaged, this concentrated load will become over 17,000 tons, and it is indeed difficult to design such a solid basement. Therefore, if the huge load can be distributed by changing the integration concept, it could give the wide design variation for the fusion DEMO.

3. Welding of Vacuum Vessel Sectors

The VV has a double wall structure and is the nuclear boundary for the D-T neutron. The water will flow in the space between two walls to reduce the penetrated neutron, where some neutron absorption materials will be inserted. The inside of the VV taken from the ITER video is shown in Fig. 4. The space in the inboard side between the VV and the TF coil is very narrow, and no access is possible from the TF coil side. In the outboard side, there is some space between the TF coils, but there will be some connecting components between the coils like the share panels and the space just behind the TF coil is limited.

The first VV sector was manufactured by Korea as shown in Fig. 5 [4]. The double wall structure is clear. All weld grooves will be welded to join the VV sectors. Depending on the welding conditions, the cross section of the VV would deform and shrink. So, the welding process must be considered totally and carefully. Also, it is noticed that the shape of the VV sector is not symmetric against the vertical load line and that it requires to keep the VV sector in vertical during being hung and lowered. When the VV of the fusion DEMO is designed, the handling procedure must be taken account.

4. Proposal of Central Cylinder Concept

As mentioned above, the fusion DEMO is the very

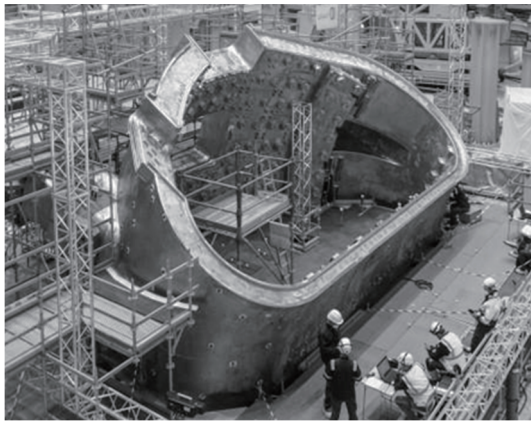


Fig. 5 First VV sector arrived at ITER site in September 2020 [4].

heavy machine. As the ITER is around 23,000 tons in total, the DEMO will be at least 76,000 tons. If it needs over 10,000 tons of cooling water for shielding the neutron and cooling the systems, the total weight increases more. Therefore, the construction site must have a very solid bedrock to support the building and the machines. The ITER complex was constructed on the limestone bedrock in France. This is one of the key issues to select the DEMO construction site.

The DEMO complex will be a semi-underground structure on the bedrock. It will have the ring-shaped basement to support the DEMO and the basement for the ceiling cranes. The crane will have a co-hanging system of which total capacity will be around 4,000 tons. It is supposed that the weight of two TF coils and the VV sector is 2,000 tons and 1,600 tons, respectively. The co-hanging system will allow the load distribution.

As in case of the ITER, two TF coils of the DEMO will be combined with the VV sector and TS. The VV sector and the TS will be loaded on the TF coil structure with bolts which will be removed after the integration. It is hard to set the joint in the inboard side, for the space is limited and there is no access to remove the bolts from TF coil side.

As shown in Figs. 6 and 7, the assembly support structure and the central cylinder will be constructed first. 18 TF coils and 9 VV sectors are supposed here. The central cylinder receives all the forces from the periphery and distributes those forces to the assembly support structures. The total weight is sustained by the gravity support. The position accuracy is the base data of the component position. No heavy load exists under the central cylinder on the slab.

One set of the assembly support structure will be removed, and the combined component will be lowered and pushed to the central cylinder. The component will be connected to the neighboring assembly support structures and the central cylinder. The gravity support will be also connected to the coil. The set position will be adjusted to

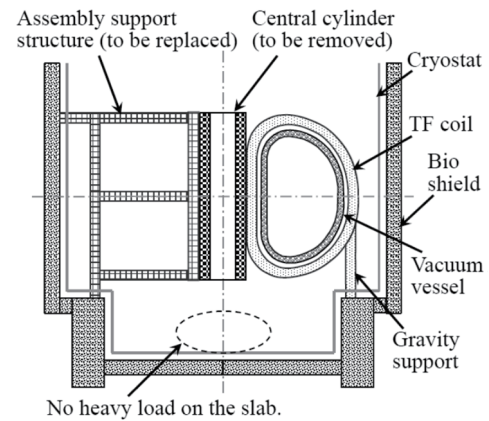


Fig. 6 Cross sectional view of central cylinder concept for assembling TF coils and VV sectors.

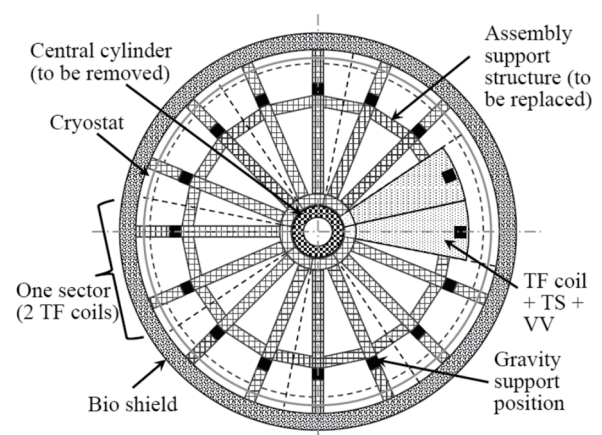


Fig. 7 Top view of assembly support structure, central cylinder and combined component.

achieve the best accuracy. The next component will be installed in the same manner at the symmetrical position. An insulation panel to break one-turn-loop will be inserted on the wedge plane between TF coils at this stage.

When all combined components are installed, the position accuracy of the TF coils and the VV sectors will be evaluated and the necessary adjustment will be performed. This integration process will be designated as a central cylinder concept hereafter.

The amount of the steels of the assembly support structure and the central cylinder is very huge, and they can be reused or recycled after the integration work. The feature of this concept is that the huge load on the device floor slab can be reduced to zero.

5. Proposal of Weld Joint of VV Sectors

Since the plate thickness of the DEMO VV sector is over 60 mm, the welding conditions and processes are different from the existing devices such as JT60SA of which

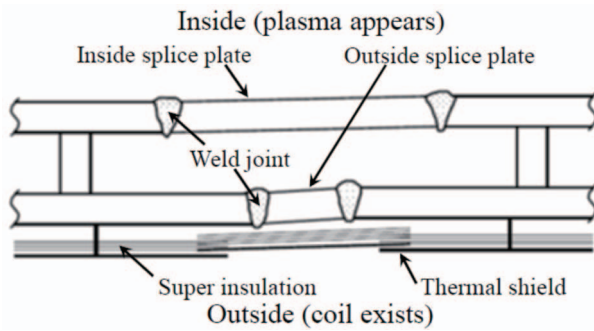


Fig. 8 Conceptual weld joint for a double wall VV sectors. Joint in outside wall is welded first, then inside splice plate is joined.

VV sector has about 20 mm thick plate [5]. All the DEMO VV sectors will be integrated and welded at the same time to make one torus structure. Some misalignment of the VV sectors should be expected, so, splice plates will be inserted between the sectors to compensate the mismatch. After the integration of the double wall components, the VV position accuracy is measured and the weld line is determined. The splice plate and the weld groove will be manufactured based on the on-site measurement results.

The conceptual weld joint is illustrated in Fig. 8. There are two walls, the inside wall and the outside wall. On the behind of the outside wall, there are the multilayer super insulation and the TS plate. So, the backing plate will be attached on the splice plate to avoid the splashing of the weld arc and the spatters to the super insulation. The splice plates for the outside wall will be set up with tack welding on the torus section and the deformation of the VV will be evaluated locally and totally. The splice plates for the inside wall will be installed after the welding of the outside wall.

A certain length will be welded at one time along the weld line and the welding heat input will be controlled to reduce the welding deformation, for the post weld heat treatment will not be carried out. The welding will proceed little by little, and the symmetric positions against the center of the device will be welded at the same time considered to control the deformation. Especially, the first pass must be carried out very carefully to avoid the defects. Since all welding positions are required to weld all torus section, the welding condition should be investigated practically before the field welding. All joints will be multi-pass welding and the weaving will be applied if necessary.

The weld joint must be inspected by the volumetric method to show the joint has high quality metallic structure and no defects. Since the backside of the outside wall is limited space by the TS and TF coil, one can access to the weld joint from only the inside of the VV. A phased alloy ultrasonic testing (UT) is one of the strong candidates to apply to the one side inspection of the thick weld joint. The material will be an austenitic stainless steel for cryo-

genic application and the UT signal will be weakened by the austenite matrix. So, the special phased alloy UT device with high resolution must be developed for this application. Some workspace is necessary for the UT inspection. So, the wide interval is prepared for the inside wall with the wide splice plate as shown in Fig. 8.

A radiographic testing (RT) will be another candidate to inspect the weld joints. It could be applied to the weld joint of the inside splice plate. The RT film will be placed in the space between the inside and the outside walls and taken out from the remained open space after the ^{60}Co irradiation. The final open space will be inspected by the phased alloy UT.

The first VV sector for ITER is shown in Fig. 7. The weld grooves are not clear in the figure, but the assembly is expected to go forward steadily.

6. Summary

The assembly and the integration processes of the TF coils and the VV sectors with the TS for the fusion DEMO are discussed including the welding of the VV sector to sector joints. The integration scenario named the central cylinder concept is proposed instead of the central support structure in the ITER. One of the key points is the huge load on the device floor under the being assembled machine. In case of the ITER, the solid and tough floor slab structure is required to endure the huge concentrated load which exists only for the integration period. The proposed scenario of the central cylinder concept does not require such a tough floor slab.

Regarding the weld joint of the VV sector to sector joint, the conceptual weld joint is proposed taking account of the integration and the welding processes. The total integration process must be established including the non-destructive inspection when the practical design is carried out. This is also one key point to be noticed.

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