Basic Concept of JT-60SA Tokamak Assembly

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The basic concept and approach for the assembly of the major components for JT-60SA are studied. The absolute coordinate system for JT-60 SA assembly and the reference positions of the major components is defined as a basis of the assembly, taking into account the different deformations of the vacuum vessel (VV) and toroidal field coil (TFC) under the conditions of assembly and plasma operation. The conceptual assembly tools, such as the assembly frame and other jigs/fixtures, are also studied and proposed for effective assembly works for the major components, such as VV and TFC. The assembly of the last TFC is a critical issue due to the friction during insertion between two adjacent TFCs in the narrow space of 20 degrees. To reduce the effect of friction, it is suggested that the opening angle for insertion of the last TFC is increased from 20 degrees to 60 degrees by combining the last TFC with the adjacent two TFCs as a single body.

Keywords: JT-60SA, assembly, assembly frame, assembly jig and fixture, assembly scenario

1. Introduction

The JT-60 SA project is a combined project of Japan (JA) - EU satellite tokamak program under the Broader Approach (BA) agreement and JA domestic program [1, 2]. The JT-60SA is planned to be constructed in the existing JT-60 tokamak building after disassembly of the JT-60U facility. Major components of JT-60SA for assembly are the vacuum vessel (VV); superconducting coils, including the toroidal field coil (TFC), equilibrium field (EF) coils and central solenoid (CS) coil; in-vessel components, such as divertor; thermal shield (TS); and cryostat. The TS is composed of three parts, those being the vacuum vessel thermal shield (VVTS), port thermal shield (PTS) and cryostat thermal shield (CTS). The JT-60SA assembly also includes the re-installation of the neutral beam injector (NBI), electron cyclotron heating system (ECH), VV-pumping system, etc., in the tokamak hall.

The assembly is planned to start in 2012, in order to meet the schedule of the first plasma in March of 2016. Based on this requirement, a collaborative conceptual study for the JT-60SA assembly is ongoing between JA and EU. Assembly studies of the sub-components such as layout of in-cryostat components and work space for piping and connection of the feeders in the cryostat are under way and preliminary level because the assembly of these components is planed around the end of 2014.

In the present paper, therefore, the proposed basic concept and approach for the assembly of the major components for JT-60SA are mainly described.

- Definition of the absolute coordinate system and the reference positions of the major components for JT-60 SA assembly, taking into account the different deformations of the VV and TFC between assembly and plasma operation
- Study of the basic scenario and sequence of the major components for JT-60 SA assembly
- Study of the typical assembly tools such as assembly frame and jigs/fixtures for effective assembly works for the major components such as VV, TFC, lower EF coils and VV ports
- Study of the assembly of the last TFC in the narrow

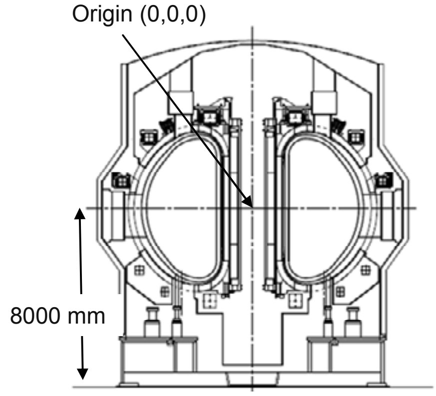

Fig.1 Absolute coordinate system of JT-60SA

author's e-mail:Shibanuma.kiyoshi@jaea.go.jp space of 20 degrees between two adjacent TFCs

2. Absolute Coordinate System for JT-60SA Assembly

The absolute coordinate system of JT-60SA is based on that of the JT-60 experimental building. The origin ((X,Y,Z) = (0,0,0)) is defined to be 8000 mm from the floor, which corresponds to a mid-plane position of the VV during plasma operation, as shown in Fig. 1.

Based on the this, the reference positions of the major components such as VV and TFC of the JT-60SA during assembly are required to be defined, taking into account mainly the thermal deformation because the operating temperature of the superconducting coils, such as TFC, and VV are 4 K and 323 K, respectively. In addition, the TS, which is an interface component installed between VV and TFC, is also considered to define the positions of VV and TFC. Figure 2 shows the results of the deformations of VV and TFC during assembly and plasma operation, respectively. The position (7998 mm) of the VV from the floor during assembly at room temperature (293 K) is determined considering the thermal expansion during plasma operation at 323 K, based on the origin of the JT-60SA device. The position (8018 mm) of the TFC from the floor during assembly is also determined, considering not only the thermal deformation at 4 K but also dead weight, deformation during coil discharge and space for installation of the TS.

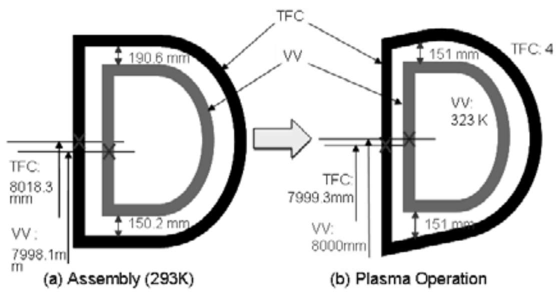

Fig.2 Positions of VV and TFC under assembly and plasma operation

3. Assembly Frame

An assembly frame, which is located around the tokamak device and provides the dedicated cranes for transfer of the tokamak components, is adopted to effectively carry out the assembly of tokamak components in the tokamak hall, independently of the facility cranes in the building for preparations such as pre-assembly of the tokamak components in the assembly hall before assembly at the tokamak hall. Figure 3 show a schematic concept of the assembly frame [3, 4]. The size of the assembly frame is approximately 16 m in height and 17 m in diameter with 10 outer vertical columns and beams between columns. The center column and guide rails are also provided in the assembly frame and used for mainly transfer, support and positioning of the TFC. In particular, the assembly of the TFC contains the toroidal movement along the pre-installed VV by the temporary supports from the assembly frame. After movement, the TFC is adjusted to a reference position and fixed by the temporary supports from the assembly frame. Therefore, the assembly frame also provides assembly tools and jigs with jacks to temporarily support the components as well as to adjust the components into their correct positions.

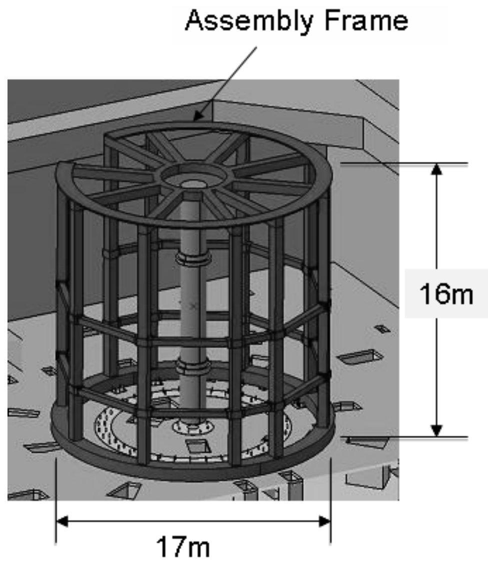

Fig.3 Assembly frame

The assembly frame is installed on the floor of the tokamak hall in the JT-60 experimental building. The existing base structures, which provide the available connection bolts, are used for the installation of the assembly frame.

4. Reference Points for Metrology

The reference points (benchmarks) for JT-60SA assembly in the tokamak hall can be defined based on those for JT-60U assembly, as shown in Fig. 4. The six reference points for JT-60U assembly were used as initial positions. From these reference positions, the virtual machine axes and the origin of the JT-60SA will be defined in the center column located at the center of the

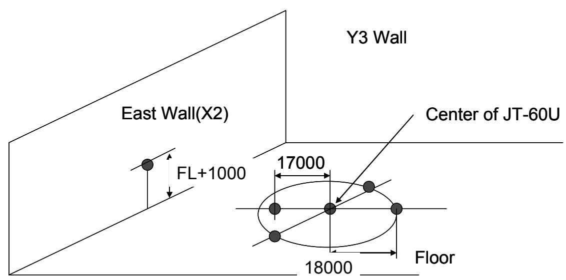

Fig.4 Reference points (benchmarks) for JT-60SA assembly in the tokamak hall

assembly frame by using the laser metrology device. Additional reference positions will be also defined on the building wall/floor and assembly frame, according to the requirements in the assembly process of the respective JT-60SA components.

5. Global Assembly Scenarios and Sequences

The basic assembly scenario and sequence of the major tokamak components are illustrated in Fig. 5.

(1) The cryostat base is installed in the tokamak hall.
(2) The first 40 degree VV sector is installed.
(3) The VVTS is temporarily supported on the VV sector (The VVTS is finally installed on the TFC after completion of all TFC installation around VV).
(4) The first TFC is installed around the VV.
(5) The remaining VV sectors, VVTS and TFCs are continuously installed, respectively, according to the same sequence of (2) to (4).
(6) The last TFC and VV sector covered by 20 degrees with VVTS are installed together.
(7) Six EF coils and CS coil are installed on the TFCs. The pre-loading of CS coil is under study, by wedge or heating as examples.
(8) The PTS is connected to the VVTS, so that the VVTS is supported by the TFCs via the PTS.
(9) The CTS body is installed and connected to the PTS after completion of piping, feeder connection, etc. in the lower space of the cryostat.

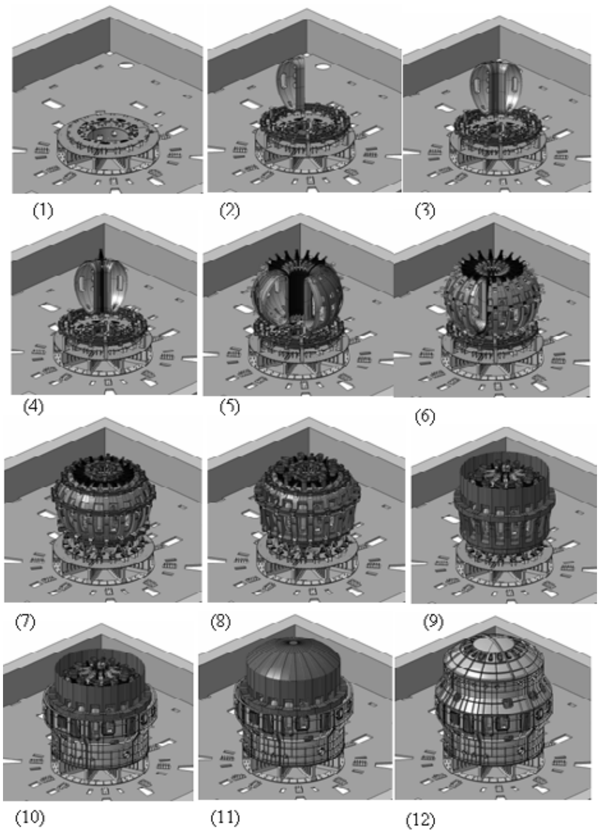

Fig.5 Basic assembly scenario and sequence of the major tokamak components

(10) The lower cryostat body is installed.
(11) The CTS lid is installed after completion of piping, feeder connection, etc. in the upper space of the cryostat.
(12) The cryostat lid is installed. After that, the VV ports are inserted and welded between VV and cryostat.

6. Assembly Jig and Fixture

6.1 Assembly Jig for VV Sector and TFC

For the assembly of the tokamak components, the assembly of the VV sector and TFC is the most critical because the VV sector and TFC are installed under close relationship in the assembly sequence. Therefore, the assembly scenario of the VV sector and TFC is described in more detail, including some preliminary concepts of jigs and fixtures for the assembly of VV sector and TFC.

Figure 6 shows a preliminary concept of the assembly jig and fixture, which is used not only for VV sector installation but also TFC installation in the assembly frame. For this, the assembly jig and fixture must be capable of:

- Positioning the VV sector during installation for welding between VV sectors
- Supporting the VV sector during TFC installation around the VV sector
- Supporting the VV sector during installation of the VV gravity support
- Supporting the VV sector against possible earthquake loads

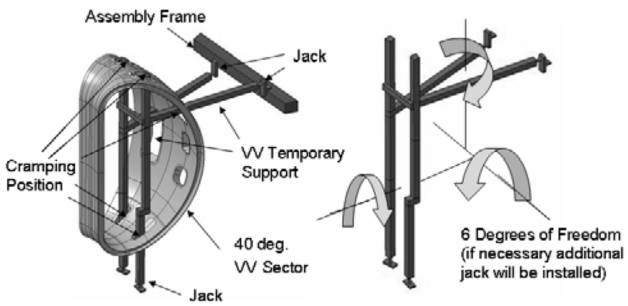

Fig.6 Preliminary concept of the assembly jig and fixture for VV assembly

To satisfy the above requirements, the assembly jig provides six degrees of freedom for positioning components, using jacks and support beams; clamp mechanisms to grasp the VV sector; and removable structure of the support beam, which avoids the interference between the support beam and the TFC during the toroidal movement of the TFC along the VV sectors.

Using this jig, the assembly sequence of the TFC around the VV sector is shown in Fig. 7. After the lower leg of the front side of the support beam is removed in stage (3), the TFC is moved toroidally along the VV sector and located at the center of the 40-deg. VV sector

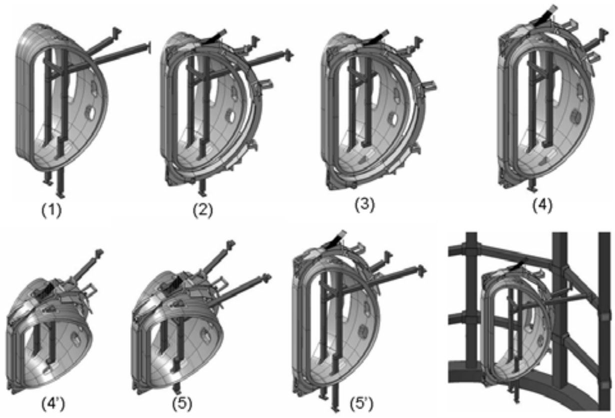

Fig.7 Assembly sequence of the TFC around the VV sector

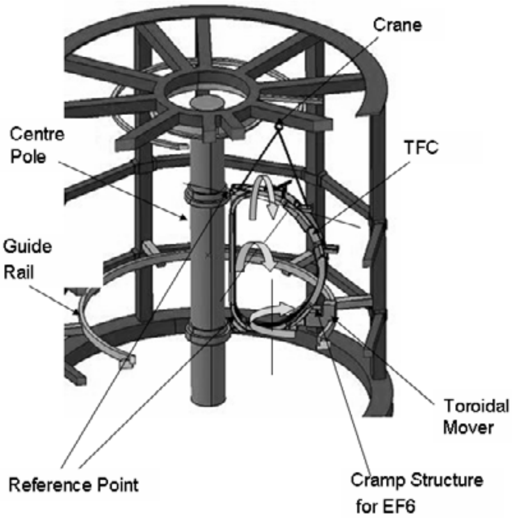

Fig.8 Schematic view of the assembly jig and mechanisms for toroidal movement along the VV sectors, support and positioning of the TFC in the assembly frame

in stage (4). During this time, the other support beam

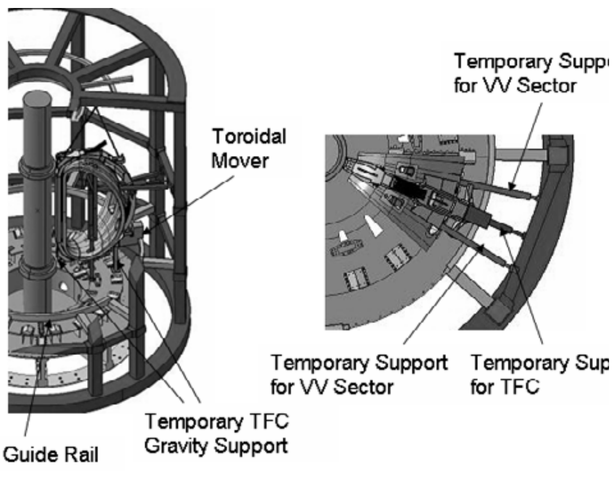

Fig.9 Preliminary concept of the assembly jig and fixture for TFC assembly

supports the VV sector from the assembly frame. After that, the lower leg of the support structure is reassembled in stage (5).

As for the TFC assembly, a preliminary idea of the jig and some mechanisms for locating and supporting the TFC in the assembly frame is studied. Further detailed study is necessary, after the clarification of the requirements of the TFC assembly. Figure 8 shows a schematic view of the assembly jig and mechanisms for toroidal movement along the VV sectors, support and positioning of the TFC in the assembly frame. The toroidal movement is carried out using the toroidal mover along the rail structures installed in the assembly frame in conjunction with the dedicated crane. The horizontal support beams with jacks from the assembly frame and the vertical support beams for temporary gravity support at the inner and outer locations from the cryostat base are used for the positioning and fixture of the TFC, as shown in Fig.9. The reference points for the measurement and positioning of the TFC in position will be adopted at the upper and lower parts of the inner wedge of the TFC. Figure 9 also shows a combination and layout of the support beams between TFC assembly and VV sector assembly. The optimized location and number of the support beams will be defined after more detailed study.

6.2 Assembly Jig for Last TFC

The last TFC (18th TFC) has to be installed with VV sector and VVTS into the opening of 20 degree after assembly of the VV sectors with 340 degrees and 17 TFCs, as shown in Fig.10. The assembly jig and fixture for the last TFC is required to be combined with that for the VV sector and VVTS. Figure 11 shows an idea of the combined jig and fixture, including the following requirements and assumptions.

- The VV sector with VVTS is supported with the last TFC.
- The last TFC is firstly installed and assembled by bolting adjacent TFCs.
- The support/fixture parts for the last TFC of the combined jig and fixture are removed for the following assembly of the last VVTS and VV sectors.

After removal of TFC support/fixture parts, the combined jig and fixture after becomes the same configuration as that for the assembly of the VV sector (see Fig.6).

6.3 Assembly Scenario of Last TFC

According to the description in section **6.2**, the last TFC (18th TFC) has to be installed into the opening of 20 degree. However, the inner wedge, in particular the upper and lower crown areas, of the TFC is required to be connected without gaps to the adjacent TFCs. It is difficult to install the last TFC without a gap in the crown areas due to friction between adjacent TFCs during insertion. To solve this problem, it is propose that the final positioning and adjustment of the last TFC is carried out together with the two adjacent TFCs. The combination of the last three TFCs leads to the increase of the opening angle to 60 degrees instead of 20 degrees.

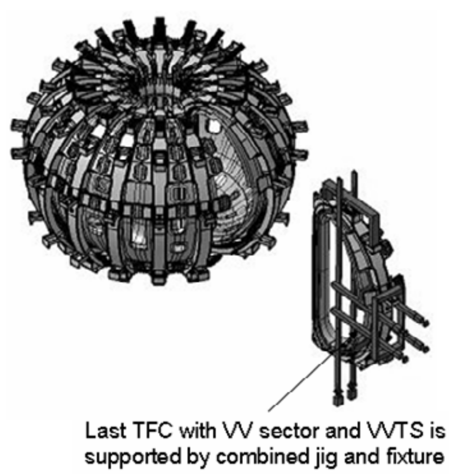

Fig.10 Last TFC (18th TFC) has to be installed with VV sector and VVTS into the opening of 20 degree after assembly of the VV sectors with 340 degrees and 17 TFCs

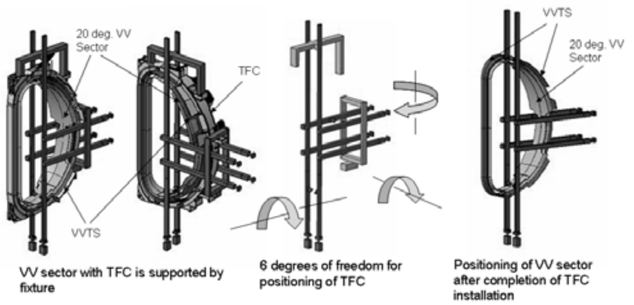

Fig.11 Combined jig and fixture for last TFC assembly

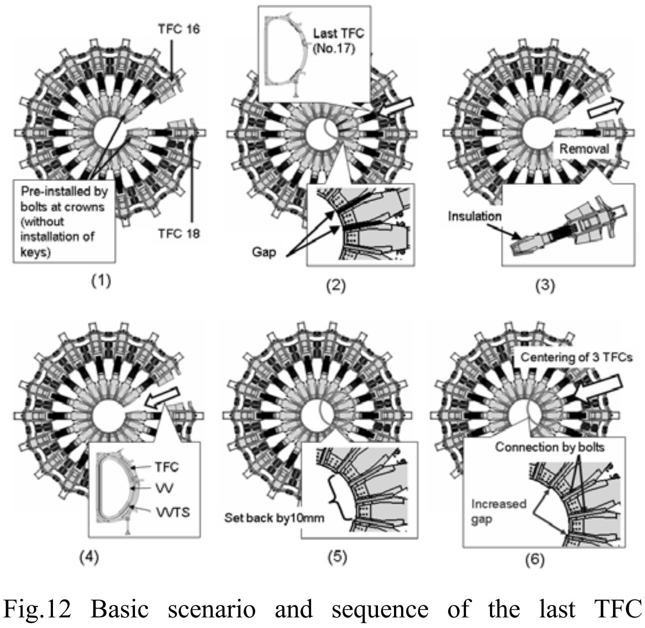

Fig.12 Basic scenario and sequence of the last TFC installation

Therefore, this scenario can reduce the problem of friction during insertion of the last TFC in the narrow opening space of 20 degrees.

Figure 12 shows the basic scenario and sequence of the last TFC installation.

(1) The installation of 17 TFCs and VV covering 340 degrees with the VVTS are assembled. At this stage, it is noted that two adjacent TFCs located on both sides of the last TFC are pre-assembled in position using temporary bolts at the crowns.
(2) To customize the insulation shims between the last TFC and adjacent TFC, the gap is measured after the insertion and pre-assembly of the last TFC between the adjacent TFCs. This pre-assembly is carried out using the last TFC only, i.e. without the associated VV sector and VVTS sector.
(3) After removal of the last TFC, the customized insulation is attached on both sides of the inner wedge of the last TFC in the assembly hall.
(4) The last TFC combined with VV sector and VVTS is pre-assembled in the assembly hall and transfered to the tokamak hall.
(5) The last TFC with VV sector is positioned shifted 10 mm radially outward from the reference position between the two adjacent TFCs. After that, the last TFC is temporarily connected with two adjacent TFCs by bolting at the crowns so as to form the last three TFCs as a single body.
(6) The last three TFCs are installed in the reference position in the opening space of 60 degrees. The assembly of the last TFC is completed by bolt and shear pin connections at the crowns of the last TFC. After the completion of all TFC installation, the respective connections of the last VVTS, by bolting; and VV sector, by welding; are carried out through the access gap between VV sectors from the inside of the VV.

6.4 Assembly Jigs for Lower PF Coils

Three lower EF coils need a special care for the installation in six EF coils. After installation of the cryostat base, three lower PF coils (EF4, EF5and EF6) are pre-installed on the jack-up systems located on the cryostat base. Figure 13 (a) shows an example of EF5 installation. After completion of the assembly of TFC, VV and VVTS, three EF coils are jacked up and installed in the right positions on the TFCs, respectively. Figure 13 (b) shows the installation position of the EF5 lifted by single staged jack-up systems. Two-staged jack-up systems will be used for the installation of EF6, whose location is higher than that of EF5. After installation of the lower EF coils, three upper EF coils are installed by the facility crane in the tokamak hall.

6.5 Assembly Jigs for VV Ports

There are many types of VV ports such as upper vertical, upper oblique, horizontal, lower oblique and lower vertical ports. In addition, the assembly of the VV ports is carried out in the restricted space between VV and cryostat, although the precise installation is required. To meet the requirements, a guide rail concept is therefore adopted. The guide rail is pre-installed between VV and assembly frame as a base structure for the positioning of the VV port, as shown in Fig. 14. In addition, the precise adjustment and fixture of the VV port are performed using the jack systems installed in the VV port, as shown in Fig.15. Installation of the VV port on the guide rail is carried out by the dedicated crane in the assembly frame. After adjustment, the VV port is welded from the inside of the VV.

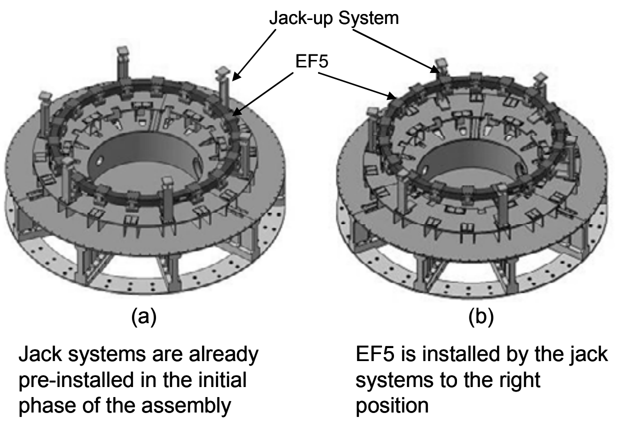

Fig.13 Basic scenario of the lower EF coil installation

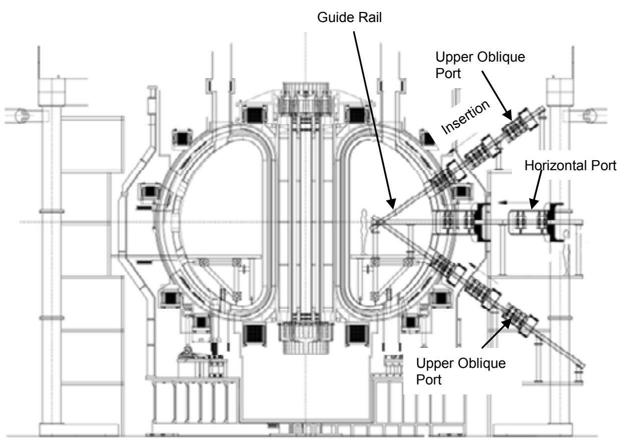

Fig.14 Basic scenario of the VV port installation

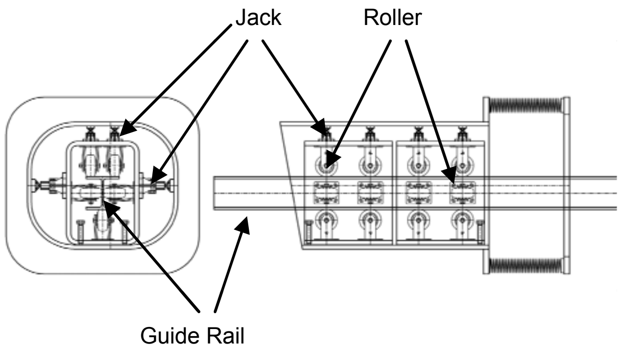

Fig.15 Concept of adjustment mechanism for VV port installation

7. Summary

The basic concept and approach on the assembly of the major components for the JT-60SA have been studied. The conceptual assembly tools such as assembly frame and jigs/fixtures have also been studied and a procedure proposed for effective assembly of the major components, including the VV and TFC. The critical issue of overcoming friction during the assembly of the last TFC could be reduced by combining the last TFC with two adjacent TFCs as a single body, so that the opening space becomes wider up to 60 degrees for the insertion of the last three TFCs.

Further to the above conceptual assembly study on the major components, additional engineering works including assembly of the in-cryostat components are ongoing with the support from industry for the JT-60SA assembly .

3. References

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