Design and structural analysis of ITER upending tool for sector sub-assembly

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\textbf{A B S T R A C T}

The purpose of the upending tool (UT) is upending the vacuum vessel (VV) 40-degree sectors and the toroidal field coils (TFC) from the horizontal delivery orientations to the vertical assembly orientations. According to ITER assembly procedure, this upending operation is carried out by four hooks of the tokamak crane. VV or TFC upended by UT is transferred to sector sub-assembly tool (SSAT) for sector sub-assembly. For this reason, UT is classified as a lifting accessory in the ITER load specification.

This paper describes UT design and upending sequence by two cranes with target components (VV and TFC) and presents the analysis results performed for the final design to verify the structural integrity of UT. The analysis cases for this verification are composed of the horizontal and vertical supporting on the floor and lifting. The simplified FE models for the lifted components (VV and TFC) that are provided from ITER Organization Central Team (IOCT) are used for this structural analysis.

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\section{1. Introduction}

The Korea Domestic Agency (KODA) of ITER project has carried out the final design of 43 in-kinds assembly tools. The upending tool (UT) is one of them. The main function of UT is raising the vacuum vessel (VV) sector or the toroidal field coil (TFC) vertically. UT and component are handled by two cranes (750t class) installed at the assembly hall.

This paper contains the design information for UT with analysis results of the seismic analysis and static analysis to verify integrity of the upending tool. For the seismic analysis, the modal analysis was performed for each model to determine the modes of the structure. Also, the spectrum analysis to determine the reactions were applied in three directions (x, y, and z) separately, using the natural vibration modes and the response spectra of ITER assembly building. The Newmark method for building reaction and Square Root of the Sum of the Squares (SRSS) method were used for that combination [1,2]. The static analysis was performed for the normal, factor, seismic and lifting cases in accordance with the ITER load specification and tooling procedure [3,4]. The deformation and Von-Misses stress of upending tool are calculated for the evaluation of integrity. The assessment was carried out according to the design criteria classified by steel structure and lifting accessory in ITER load specification [3] and EN codes [5–7].

\section{2. The design of upending tool}

\subsection{2.1. Components for 40° sectors sub-assembly}

The single 40° sector consists of a vacuum vessel (VV), a vacuum vessel thermal shield (VVTS) and two toroidal field coils (TFCs) with bracing tools as shown in Fig. 1. The VV or TFC needs the upending motion for sector sub-assembly according to the assembly procedure. After the VV or TFC is set vertically with UT, it is transferred by cranes from upending tool to sector sub-assembly tool (SSAT). The SSAT is the device in which the VV, VVTS, and TFCs are integrated to form the assembly unit (40° sector), on which the in-pit assembly of the Tokamak is based [8].

\subsection{2.2. Upending tool}

Overall size of UT is 15.0 m (L) x 12.5 m (W) x 6.15 m (H) and weights of only UT are 242,243 kg including VV temporary supports and 252,224 kg including TFC temporary supports, respectively.
These masses come from CATIA 3D model. TFC and VV sector are mounted on the upending tool and fixed by the bracings and clamps. The upending operation is achieved by using four hooks of the main tokamak crane, as shown in Fig. 2.

The upending tool is comprised of upending frame, component interfaces (clamps, supports and component touching surfaces) and mechanical anchoring as shown in Fig. 3. The upending frame is the main part of upending tool. It consists of transverse and longitudinal beams designed the weight distribution of the component. The full penetration welding applies to welding connections of transverse and longitudinal H-beams, and the integrity of the H-beams is verified through the structural analysis.

The upending tool shall be designed to have adequate structural resistance. Structural resistance means that the structure shall have enough strength capacity of a member to withstand actions with mechanical failure. Structural design by the partial factor method in chapter 6 of EN-1990[5] is applied for the assessment. Some parts or points can't be assessed by FE (Finite Elements) analysis due to its simplification or boundary conditions. So, structural reliability of the parts or points was assessed by engineering calculation. These parts such as bolts, fillet weld connection, pin and commercial components were verified by calculation according to EN codes[6,7].

### Table 1a

<table>
<thead>
<tr>
<th>Tool Classification</th>
<th>Load Combination</th>
<th>Design Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting Accessory</td>
<td>$\gamma_c \cdot D F_1 \cdot P L + T i l t$</td>
<td>EN 13155sec. 5.1.1, Annex A[6]</td>
</tr>
<tr>
<td>Steel Structure</td>
<td>$\gamma_c \cdot D F_1 \cdot \gamma_{0.1} (D F_3) \cdot P L + \gamma_{0.2} \cdot H L_5$</td>
<td>EN 1993-6[7]</td>
</tr>
</tbody>
</table>

Note: Tilt - Forces due to imposed tilt of the lifting accessory (minimum 6°).

HLS - Horizontal load for steel structures, minimum 0.05 g horizontal acceleration applied to the payload (non-factored) and to the dead weight of the tool (non-factored) in any direction causing the maximum stress in the part being considered.

DF1 - Dynamic factor for lifting accessories, 2.0.

DF3 - Dynamic factor for steel structures, 1.15.

$\gamma_c$ - Partial factor for dead weight, 1.35.

$\gamma_{0.1}$, $\gamma_{0.2}$ - Partial factors for variable crane loads, 1.35.

SL-1 - Seismic Load.

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