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The ITER EC H&CD Upper Launcher: Maintenance concepts

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HIGHLIGHTS

- We explain how an overall maintenance strategy defines individual maintenance tasks.
- Concepts are presented for replacement strategies of the in-vessel optical components.
- Vertical placement of the Upper Launcher in the Hot Cell may simplify maintenance.

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ABSTRACT

Maintenance of the ITER EC H&CD Upper Launcher (UL) shall be performed through the use of Remote Handling (RH) in the ITER Hot Cell Facility (HCF). The UL design will have to be fully compliant with ITER RH maintenance requirements and the set of RH tooling and services available in the HCF. This paper describes the development of an overall maintenance strategy for the UL, starting from a listing of all conceivable maintenance operations, including hands-on tasks. Components for which design concepts are discussed in this paper are the Blanket Shield Module (BSM), the steering mirror (M4), the mid optics (M1, M2) and the waveguide (WG) feed-through plate. Aspects related to RH documentation, overall maintenance strategy and design concepts for optimizing the maintainability of the UL are presented.

1. Introduction

The EC H&CD (Electron Cyclotron Heating & Current Drive) Upper Launcher (UL) [1,2], is part of a system that provides localized heating and current drive to the plasma, allowing an active control of MHD activities that might represent a potential threat for tokamak operations. It is being designed by the European ECHUL-CA consortium, to be integrated into 4 of the ITER Upper Port Plugs (UPP), that will be installed in upper ports 12, 13, 15 and 16. The basic layout of the UL (Fig. 1) consists of a set of 8 waveguides (WG) that enter the UPP from the rear, followed by 2 mirrors (M1/M2) in a dog-leg configuration that are called the Mid-Shield Optics (MSO). Inside the hollow Blanket Shield Module (BSM) on the plasma facing side of the UL, a focusing mirror (M3) and two Steering Mirror Assemblies (SMA) are located.

Although the UL is designed to last for 20 years of ITER operation, it is likely that maintenance is required at some point during its life time. Like any other system that is integrated into the ITER Port Plugs, such maintenance shall be performed in the Hot Cell Facility (HCF) through the use of Remote Handling (RH) [3]. Procedures thereto have a profound impact on the design of the maintainable component and therefore a mandatory Remote Handling Compatibility Assessment (RHCA) is to be performed for any in-vessel component that requires maintenance. Due to limitations in vision, dexterity and haptic feedback while operating the robotic manipulator, inaccessibility of the plant (object to be maintained) and high stakes of the maintenance operation, the design of the plant should be optimized for maintenance through the RHCA and the RH procedures described in advance.

This paper describes the recent progress toward that goal with regards to maintenance documentation, its database of tasks and tools and proposes conceptual design features necessary to make the UL design RH maintenance compatible. The presented design concepts are currently not part of the baseline UL design and are in the process of evaluation within the ECHUL-CA consortium.

2. Remote Handling documentation

ITER RH requirements are well established and can be found in the ITER Remote Handling Code of Practice (IRHCoP) [3] and the

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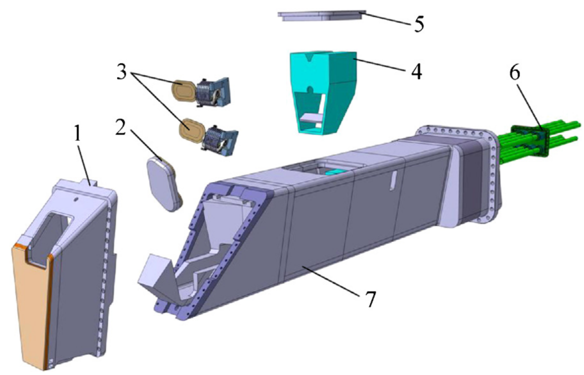

Fig. 1. Exploded view of the UL, identifying all RH maintainable components: 1 – BSM; 2 – M3; 3 – SMA; 4 – MSO-block, containing M1 and M2; 5 – bottom hatch; 6 – WG assembly including feedthrough plate; 7 – UPP structure.

ITER Remote Maintenance Management System (IRMMS) [4]. These documents state that maintenance procedures should be described in Task Definition Forms (TDF), while the plant, together with the contextual environment where such maintenance is performed, is described in Plant Definition Forms (PDF). Both TDF and PDF are important documents since these effectively describe the maintenance procedure. The Operations Sequence Description (OSD) is an 'advanced' TDF, since it describes every detail of the procedure like a story board. Additionally, animations will be made of critical maintenance operations to demonstrate their feasibility. The required level of detail in which maintenance activities have to be described, depends on the RH classification, which is described in [4]: "[. . .] Classification is based on the need for scheduled or unscheduled maintenance or modification, and the likelihood of maintenance as determined by the plant designers, and on the impact of the maintenance procedure on ITER operations and availability [. . .]".

A first order indexation of all maintenance tasks related to the UL, including hands-on activities in the port cell, resulted in a list of 65 TDF and 8 PDF. Typically these tasks can only commence after successful completion of a preceding task. Such inheritance, together with the substantial amount of described tasks, requires careful tracking of changes in the design, tools and procedures for which currently no QA methodology is described.

Part of our effort toward designing an RH compatible Upper Launcher is therefore focused on creating a dynamically interlinked document database filled with standardized sub-procedures (like a programming language) that makes the maintenance directory for the EC system more transparent and robust. The aim is to make this directory available to IO as part of the design documentation to be reviewed at the Final Design Review of the UL. Recently, a detailed plan for the establishment of an ITER Maintenance Directory (IMD) [5] has been put forth. The IMD will list all maintenance activities for all ITER systems. The development of the UL maintenance database is aimed at full compatibility with the IMD.

3. Remote Handling strategy

Describing maintenance tasks requires knowledge about the available space (workspace, storage, waste), equipment (tools, cranes, cameras) and services (vacuum, pressurized air, electricity etc.). Since ITER resources and currently available knowledge in this respect is limited, the need arises for an overall strategy involving standardization of all of the above, with the aim to minimize the burden of UL maintenance on all interfacing systems.

Although the IRHCoP offers examples for tooling, procedures and design features that have and are being used at JET, it is not complete enough to offer off-the-shelf solutions for all foreseen tasks on the UL. This is mainly a matter of scale, since ITER is simply a bigger machine. Especially for tools, the provided solutions are often inadequate. Listed universal RH bolting tools for instance are limited to sizes up to M20 bolts.

Another issue in relation to scale is the handling of tools and components/subassemblies during maintenance, in combination with the required accuracy of positioning. The dexterous robotic manipulator arms as used in the ITER HCF have an expected maximum load capacity in the order of 25–50 kg, while the removable UL Blanket Shield Module (BSM) weighs close to a metric ton. We could design the interfaces between replaceable parts such that most if not all RH (dis-)assembly of parts can proceed along a straight vertical line. In that case, we simply use the overhead crane inside the HCF for lifting and handling. For removal and installation of the WG assembly to proceed in this fashion, this would mean having to place the 6 m long UL in a vertical position – something that is currently impossible due to the limited height between the HCF overhead crane and the floor of 6.45 m. An IO Task Order on the pre-conceptual phase of the Hot Cell RH systems design is currently running, which aims to address the feasibility to implement the refurbishment process in the current Hot Cell building. That study assumes, as input, vertical configuration of upper and equatorial plugs as a requirement for the design of the HC RH systems.

An offered solution might be to increase clearance above the plant by partly lowering the UL into the access hatch to the lower floor that is located inside the HCF maintenance area. Determining the validity of this proposal requires strong interaction with the IO sections responsible for the HCF and RH, since the hatch will be temporarily blocked during this operation. A more in-depth discussion on 'vertical handling' of the UL is described in [6].

In short, the IRHCoP offers a good starting point for development of the UL RH strategy, but it does not provide off-the shelve solutions for all tooling. Where information is currently unavailable, we develop our own tools, procedures, documents and design features that we hope can – at least partly – be merged with the IO Code of Practice. This means that the solutions presented in this paper are often still being discussed and will benefit from feedback from peers and all other stakeholders.

4. Design and maintenance concepts

4.1. Blanket Shield Module

The BSM, which is the plasma facing component of the UL is an actively cooled shield that is bolted to the front of the UL structure [7]. Replacement of the BSM is a RH-class 3 task.

Earlier studies [8] have indicated that the task of removal and installation of the BSM is best to be performed with the UL rotated upside down. The angle of the BSM flange is oriented to enable (dis)assembly by the HCF overhead crane, in combination with a tilting movement guided by a hinge. Recent studies [7] have led to an BSM flange design that is better suited for Remote Handling than the PDR design depicted in [8], in which no specific RH features were integrated.

4.2. Steering mirror assembly

The SMA (RH-class 3) are located directly behind the BSM and are mounted to the UL structure. It is currently foreseen that the UL structure will have accurately machined surfaces to which all optical elements are mounted. The UL structure will therefore effectively become an optical bench to ascertain that the required alignment of the optics can be achieved.

Two designs have been made of the SMA support structure, of which the first was presented in [8]. A disadvantage of that design was that a specific welding tool would have to be developed to

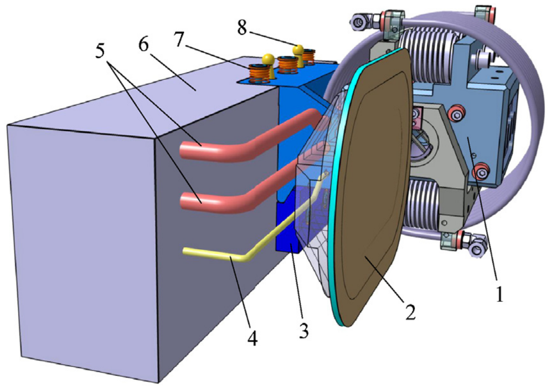

Fig. 2. A new proposal for the SMA support structure: 1 – steering mechanism; 2 – mirror; 3 – wedge plate; 4 – He actuation line; 5 – cooling lines; 6 – UL structure; 7 – RH pop-up bolts; 8 – guiding pins.

reweld the cooling and He actuation lines. This resulted in further studies to find ways of mounting the SMA using more generic tools, as listed in the IRHCoP.

A new proposal, depicted in Fig. 2, follows a more basic approach. In it, the SMA support is constrained by a wedge plate and two guiding pins, and fastened by three RH compatible pop-up bolts. The cooling pipe and He actuation line run sideways and can be accessed from above by orbital cutting and welding tools, that are described in the IRHCoP. Although the precise tooling dimensions and required alignment features have not yet been used to check accessibility, this design offers sufficient margin to adapt to specific tooling requirements. The minimum distance between pipes in this design is 42 mm, which is more than $\frac{1}{2}D + 25$ mm, as mentioned in [3]. To create space for the tooling when cutting the three lines, a large section is removed from the uppermost line, a smaller section from the middle line and the smallest section from the lower He line. Alternatively, the lines can be accessed from the side – or the front, when seen as in Fig. 2. Upon restoring the connections, new pipe sections are installed that compensate for the lost pipe length due to cutting.

4.3. Mid-optics

The dog-leg mirrors M1 and M2 are located in the mid section of the UL. These mirrors are classified as RH-class 3 and therefore require an RH-compatible replacement strategy. Earlier designs of the EC H&CD UL contained an internal shield block that held the M1/M2 mirrors in place (MSO-block). Replacement of any of these mirrors required extraction of this shield block from the plug, after which the block would be exchanged with a replacement in its entirety. The mirrors inside the block can be refurbished or replaced offline, or the block can be stored as RAD-waste.

A trade-off between maintenance time, spare part requirements, stiffness of the UL structure and overall accessibility leads to the tentative conclusion that access from the sides of the UL is a more preferable option. The current proposal is to mount the mirrors in rows of four onto a module that can be extracted through an aperture in the side wall (Fig. 3). Per module, only 2 cooling lines need to be cut and a minimum amount of bolts need to be undone to unload the module. The modules themselves are mounted to the UL structure, which itself is the optical bench, as described in Section 4.2. This design has apertures on either side of the UL structure; one side provides access to the lines to be cut (Fig. 4), while the module is extracted from the opposite side (Fig. 3). Further optimization may lead to a design with a single aperture on one side of the UL for both.

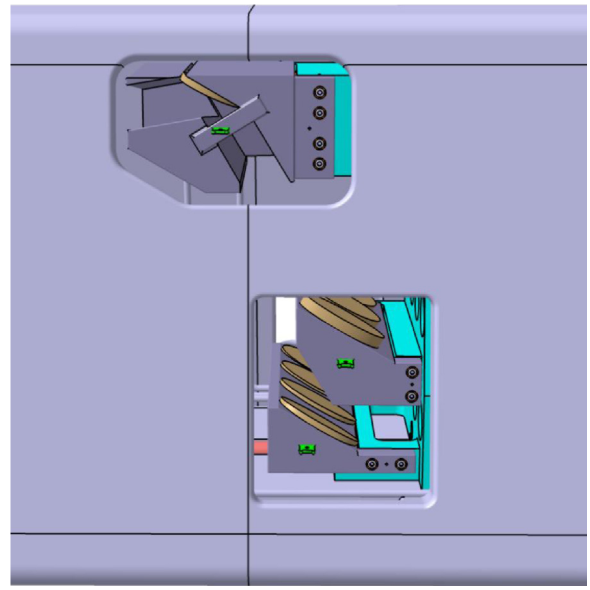

Fig. 3. Small access holes on one side of the UL structure give direct access to the M1 (lower) and M2 (upper) mirror assemblies.

4.4. Waveguide feedthrough

The UL contains 8 circular waveguides that are mounted into the rear (ex-vessel) side of the Port Plug onto a feedthrough plate in two rows of four (Fig. 5) [9]. Replacement of the assembly is RH-class 3. The current baseline approach is that the entire assembly is replaced if a defect in one of the waveguides is found. The reason being that the individual lines are placed close together and access with tools to each individual line may be problematic when using RH. Refurbishment of a single line can be performed off-line, leading to the possibility to re-use the WG assembly.

Replacement of the assembly as a whole can be performed with the UL either in a horizontal or a vertical orientation. Handling and positioning of the waveguide assembly in a horizontal orientation is more complicated since this requires the assembly (~350 kg) to be inserted into the launcher in a cantilevered fashion, over a distance

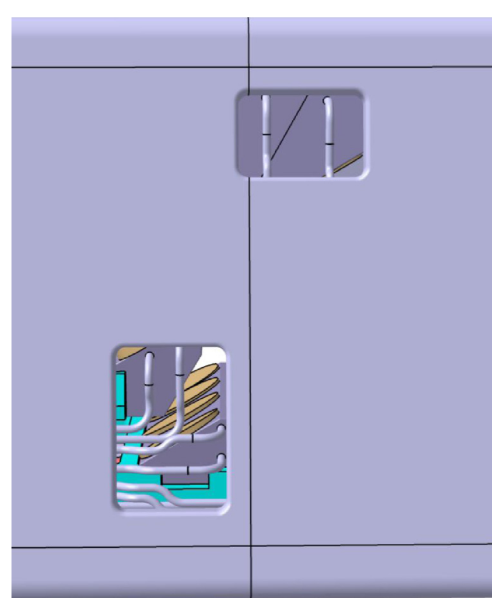

Fig. 4. The opposite side of the UL, containing access holes to the cooling pipes of the M1/M2 assemblies.

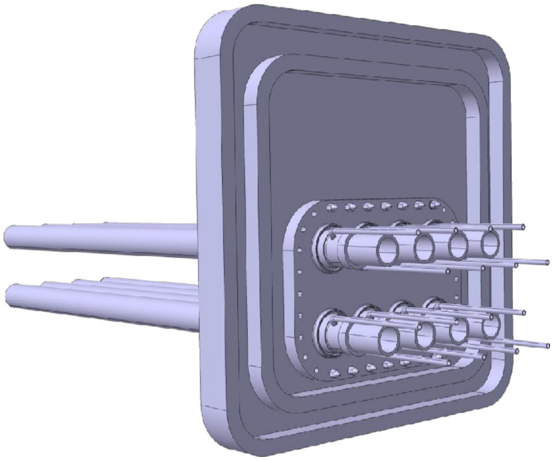

Fig. 5. Baseline design of the UL closure plate assembly, which shows the 8 WGs mounted on the feedthrough plate that is bolted to the closure plate.

of close to 3 m. Alternatively, the launcher is positioned vertically, as described in Section 3, with the rear of the launcher pointing upwards. After undoing all the bolts and breaking all interfaces, the assembly containing the feedthrough flange and all eight waveguides can be lifted out by the HCF overhead crane. Assembly can also be performed with assistance from the crane, allowing for gravity assisted handling.

We performed a study, both for a vertical and horizontal orientation of the plug, on whether an alternative strategy is conceivable by replacing the waveguides individually. It became clear when the design was reviewed from a maintenance perspective, that the vacuum seal is located too deep inside the rear of the UL structure to have proper tooling access to the flanges. A solution for this is to extend the support pipes surrounding each waveguide backwards by ∼400 mm (Fig. 6).

The study indicated that the vertical orientation of the Port Plug is preferable. Otherwise, as with replacing the WG assembly as a whole, the individual WGs would have to be inserted in cantilevered fashion, leading to a high risk of jamming/wedging inside the support pipe. A proper design of the hoisting interface of the individual waveguides will guarantee that the part is suspended vertically (Fig. 7).

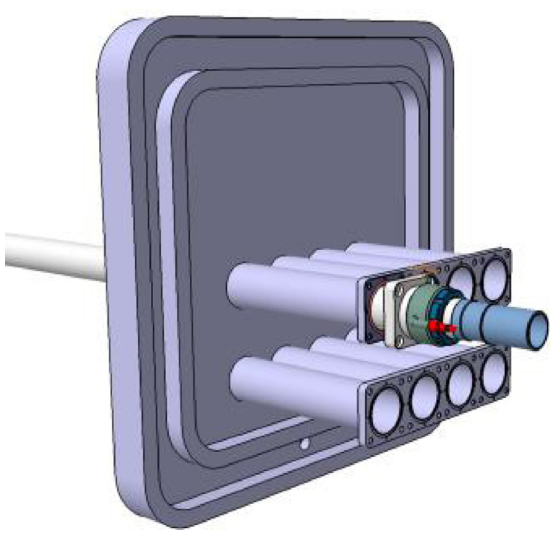

Fig. 6. Proposal for the UL closure plate assembly, containing individual support pipes and bolted flanges for each of the 8 waveguides.

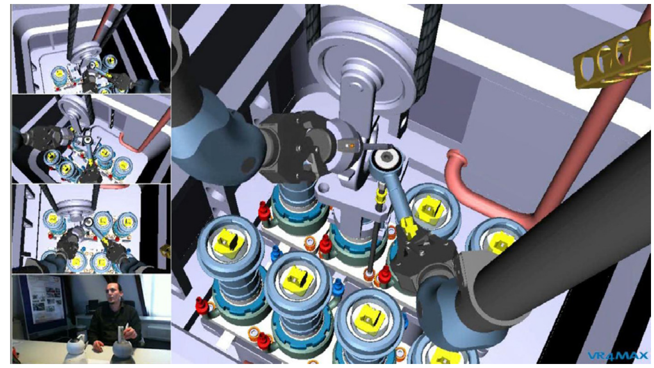

Fig. 7. Screenshot of a real-time simulation of a concept replacement procedure of one of the waveguides. The dexterous manipulator arms handle a bolting tool and a torque multiplier (both listed in the IRHCoP). A crane hook is attached to one of the WGs. On the left side, alternative camera views provide more information on the work scene.

4.5. Hands-on maintenance

Part of the EC Upper Launcher system is located in the Upper Port Cells at the back of each plug and behind the bioshield (Fig. 8). Both for maintenance purposes and for clearing the port for docking of the transfer cask, access is required. It should be noted that Fig. 8 does not show all auxiliary equipment that will be located inside the port cell. Missing items that contribute to the time needed to clear the port cell include the WG support structures, He actuation system, cooling manifolds, vacuum lines and/or pumping systems, CODAC, etc.

The bulk of activities inside the port cell is expected to be performed hands-on, resulting in a certain level of exposure of maintenance personnel to moderate levels of ionizing radiation. To aid in the minimization of such exposure, the design team of the EC H&CD UL is looking into the ex-vessel maintenance activities with a similar level of detail as for the RH maintenance. This implies that we map all conceivable activities inside the port cell and provide Plant and Task Definition Forms (PDF/TDF) for individual tasks. Activities with a high likelihood, such as replacement of an isolation valve, window, or disassembly of the Transmission Lines (TL) will be described in more detail, meaning that OSDs and possibly Virtual Reality animations/simulations will also be prepared.

5. Summary and conclusions

In this paper, a number of features are presented to make the design of the ITER ECRH UL compatible with the IO RH maintenance requirements. In particular, conceptual solutions are presented for replacement strategies of the in-vessel optical components that require partial disassembly of the UPP structure. It is shown that side access to the M1/M2 is preferable from a maintenance

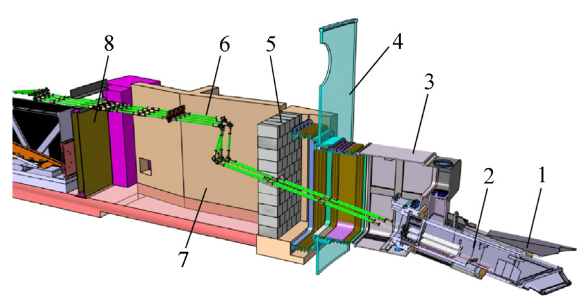

Fig. 8. Cross section of the Upper EC H&CD launching system, mounted into the port: 1 – upper port; 2 – UL; 3 – port interspace/duct; 4 – Cryostat; 5 – bioshield plug; 6 – Transmission Lines; 7 – port cell; 8 – port cell door.

perspective and that individual replacement of the waveguides may be possible, despite the baseline approach to replace all eight of them at once.

An alternative design of the SMA support structure was presented and it was explained how tooling requirements and availability in the IO RH tool database can drive a design, as well as the overall maintenance strategy. The relationship between individual maintenance tasks was explained and how this reflects on the maintenance strategy. Finally we explained how we intend to approach the hands-on maintenance tasks foreseen in the Upper Port Cell.

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