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# Interactive virtual mock-ups for Remote Handling compatibility assessment of heavy components

J. van Oosterhout[a,*], C.J.M. Heemskerk[b], J.F. Koning[b], D.M.S. Ronden[a], M. de Baar[a]

[a] FOM Institute DIFFER (Dutch Institute for Fundamental Energy Research), Association EURATOM-FOM, Partner in the Trilateral Euregio Cluster, PO Box 1207, 3430 BE Nieuwegein, The Netherlands
[b] Heemskerk Innovative Technology B.V., Jonckerweg 12, 2201 DZ Noordwijk 6, The Netherlands

## HIGHLIGHTS

- Specific ITER components require RHCA on hardware mock-ups.
- Hardware mock-ups are expensive and have a long lead time.
- Interactive Virtual Reality mock-ups are readily available and easily adapted.
- This paper analysis and proposes improvements to simulator capabilities.

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## ABSTRACT

ITER standards Tesini (2009) require hardware mock-ups to validate the Remote Handling (RH) compatibility of RH class 1- and critical class 2-components. Full-scale mock-ups of large ITER components are expensive, have a long lead time and lose their relevance in case of design changes. Interactive Virtual Reality simulations with real time rigid body dynamics and contact interaction allow for RH Compatibility Assessment during the design iterations.

This paper explores the use of interactive virtual mock-ups to analyze the RH compatibility of heavy component handling and maintenance. It infers generic maintenance operations from the analysis and proposes improvements to the simulator capabilities.



## 1. Introduction

ITER operation requires plant maintainability by Remote Handling (RH). Handling of heavy ITER components – that can weigh up to 45 tonnes – is complicated as the load cannot be controlled with taglines and because no personnel are present at the location of the load for manual alignment of the components. Operators are remote from the task and there is poor (visual and haptic) feedback. Although the task and equipment are specifically designed for an optimum workflow, many ITER tasks will require 6 degrees of freedom of movement with additional complications such as:

- Co-operators jointly controlling e.g. a dexterous manipulator and an overhead crane.
- Changing force balance during the load transfer from the crane or manipulator to the mount.
- Changing contact constraints of the system during placement.
- Structural deformation of both plant and equipment during the load transfer (e.g. [1]).
- Accurate placement requirements.

As a consequence, the RH Compatibility Assessment (RHCA) of heavy components maintenance procedures is challenging. The use of mock-ups is required by the ITER [2] for all RH class 1 and specific class 2 components. The draw-back of mock-ups however is that their construction is time consuming, expensive and only cost effective in a late phase in the design. If the design does not comply or changes due to other reasons, the full design cycle has to be repeated, including those aspects that are not associated with the maintenance. Moreover the validity of hardware tests is jeopardized in case the design of the interfaces evolves.

To improve the effectiveness of the RH compatibility assessment, early concept validation is proposed using Interactive Virtual

* Corresponding author. Tel.: +31306096932.
*E-mail address:* j.vanoosterhout@differ.nl (J. van Oosterhout).

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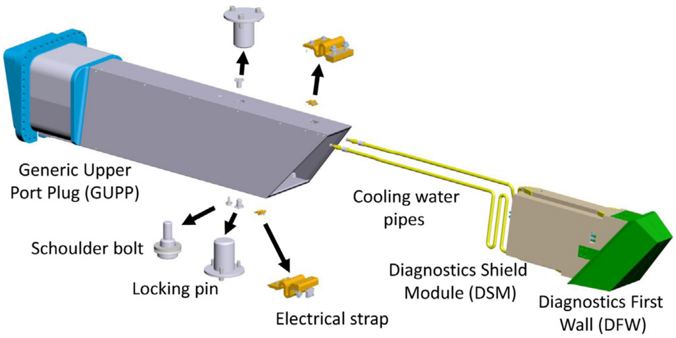


**Fig. 1.** Exploded view of the GUPP.

Reality (VR) simulation with real-time rigid body dynamics and contact interaction [3–5]. A VR mock-up is readily available and easily adapted. In case of a design change in components or their interfaces, the assessment can instantly be repeated. The merit of using VR mock-ups is that the VR simulation realistically identifies potential conflicts and non-ideal situations. Rigid body dynamics does have its limitations in case of critical operations with structurally deforming objects. As an example, in the DTP2 the divertor modules, cantilevered in the Cassette Multifunctional Mover equipped with Second Cassette End Effector (CMM/SCEE), deform ~80 mm over there length of ~3.6 m [1].

This paper illustrates the use of an interactive rigid body VR mock-up for a Remote Handling Compatibility Assessments of heavy objects in the Generic Upper Port Plug (GUPP) [6]. Improvements to the simulator are proposed, notably, in stability and accuracy for heavy object manipulation. The results from the analysis in this paper will help to define requirements for simulator updates. Finally, generic maintenance operations are inferred from the analysis. The analysis is done with an advanced interactive Virtual Reality simulation called Interactive Task Simulator (ITS).

## 2. The VR setup

The basic functionalities of ITS are discussed in [3–5]. Over the last two years, the ITS has been improved significantly, both in speed and accuracy for simulating rigid object handling.

The simulations are based on CATIA models. These models are prepared in 3DS MAX for real-time rendering and physical behaviour. Specific material, contact dynamics characteristics and robot definitions are added. The real-time rigid body dynamics, joint solver and contact interaction are simulated with NVIDIA PhysX. Typical simulation step times range from 1 to 5 ms.

Interaction with the Virtual Reality is offered by a Haption Virtuose$^{TM}$ 6D35-45, a joystick and keyboard. The Virtuose has been implemented for some time now to actuate various virtual slave devices. New in the setup is robotized structures – such as cameras, the overhead crane and even the crane-mast-boom system – which can be controlled with a joystick or keyboard.

## 3. The Remote Handling task

The analysis of heavy load tasks follows through a Remote Handling Compatibility Assessment [2] on the Diagnostics Shield Module (DSM) performed for the ITER Diagnostics department. The assessment is described in [7]. The relevant components are described in this section.

The 9 tonne DSM is inserted – as a front section – into a 10 tonne Generic Upper Port Plug (GUPP) structure (Fig. 1). In operation, the DSM is protected from the plasma by the Diagnostics First Wall (DFW). Cooling water is supplied via two pipes attached to the DSM which extend through the closure plate to the back end of the GUPP. Other interfaces between the GUPP and DSM are two Locking Pins, two Electrical Straps and a Shoulder Bolt (M30). In the Hot Cell Facility the GUPP is mounted in a (conceptual) Upper Port Plug Vertical rotator device.

The DSM handling requires hoisting and transportation by an overhead crane. In the development of the DFW [8], a pre-conceptual DFW/DSM handling tool is proposed with limited specifications. The design is expected to mature. Nevertheless, a first RHCA could be carried in VR.

The removal of the shoulder bolt will be done by a powered tool, such as the hydraulic bolting tool in the ITER RH Code of Practice (IRHCOP) [9].

## 4. Heavy load task analysis

The DSM removal procedure contains four steps in which heavy components are handled:

- Remove the locking pin
- Place the hydraulic bolting tool
- Place the DSM handling tool
- Extract/insert the DSM

### 4.1. Remove the locking pin

The mass of the locking pin is about 1 kg, which does not require special handling tools and is actually not heavy. Nonetheless, the handling procedure is likely to be subjected to heavy loads as the insertion and removal are characterized by a tight fit (H7/g6) peg-in-hole (Fig. 2). Handling of the component is therefore likely to cause jamming and may involve high torques and forces on the manipulator exiting structural compliance of the crane-mast-boom behind it.

As the simulator includes dynamic contact interaction simulation capabilities, it can simulate the contact forces and jamming. However, such a simulation with rigid bodies means that opposite surfaces experience high contact forces, which might result in unrealistic behaviour or even instability. Therefore several jamming and anti-jamming features were tested to investigate the simulators ability and quality of handling tight fits and jamming.

One of the most convincing tests concerned the jamming behaviour of a peg-in-hole task with two short g6 sections at the front and back end of the peg and a H7 hole (Fig. 3). In the real world, when only the first section of the peg is in the hole, such a peg jams on a minute misaligned insertion force. The peg will move easily when both sections are in the hole. For the VR test, the peg was modelled by two 50 mm square rigid bodies (as flat surfaces are more accurate in a triangulated model). Subjectively measured, the model reproduced reasonable and stable behaviour with the following configuration: 0.01 mm

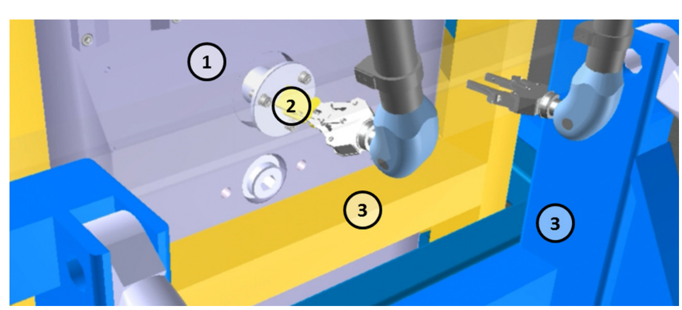


**Fig. 2.** Example of a short tight fit peg-in-hole task: placement/removal of the locking pin. (1) GUPP bottom wall; (2) locking pin; and (3) vertical rotator device.