F4E_D_35YWCA v1.3

TECHNICAL NOTE

BRIEF OVERVIEW OF THE DIVERTOR REMOTE HANDLING SYSTEM

Abstract

Information is presented regarding the Divertor Remote Handling System. This is a novel, remotely operated, electromechanical system designed to transport and accurately position (<5mm) Divertor Cassettes (each representing a load of approximately 10 tonnes). The system is also to undertake the installation of these Cassettes, involving pipe cutting, welding and other special operations using a robotic arm and dedicated tooling.

An overview of the Divertor Remote Handling System, its sub-systems (consisting of "Movers" and Remote Handling Tooling), its Control System and related Technology is provided.

The (radiation free) operating conditions specific to Machine 1st Assembly are also described. These make possible the presence of operators and, with their assistance, the use of simplified versions of the DRHS Movers.

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1. Divertor Remote Handling System

Due to neutron activation and radioactive contamination during operation of ITER, the maintenance of within its vacuum vessel will require the use of remotely operated equipment. One part of this maintenance is the removal and replacement of the divertor cassettes situated around the base of the vacuum vessel. This task will be performed by the **Divertor Remote Handling System (DRHS)**.

The divertor is broken down in 54 cassettes that can be accessed from 3 lower ports, each at 120° toroidal angle to the other (Fig. 1). Each cassette weighs approximately 10 tonnes. The cassettes can only be removed serially, starting with the ones located at the access ports.
The DRHS will be used for the 1st assembly of the divertor (with no radiation), its final removal during decommissioning and possibly for cassette changeover during operation with each one of the 3 ports utilized in series.

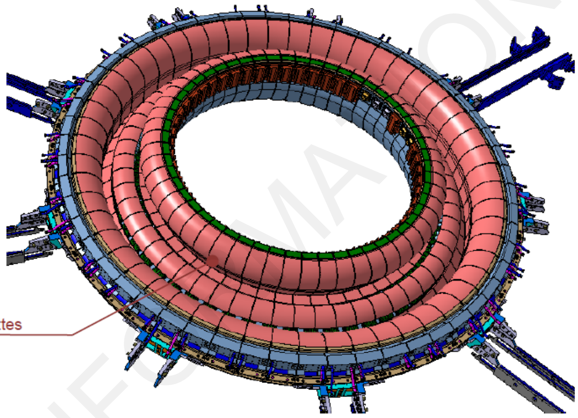


Figure 1: Configuration of Divertor Cassettes in the ITER Tokamak Reaction Vessel

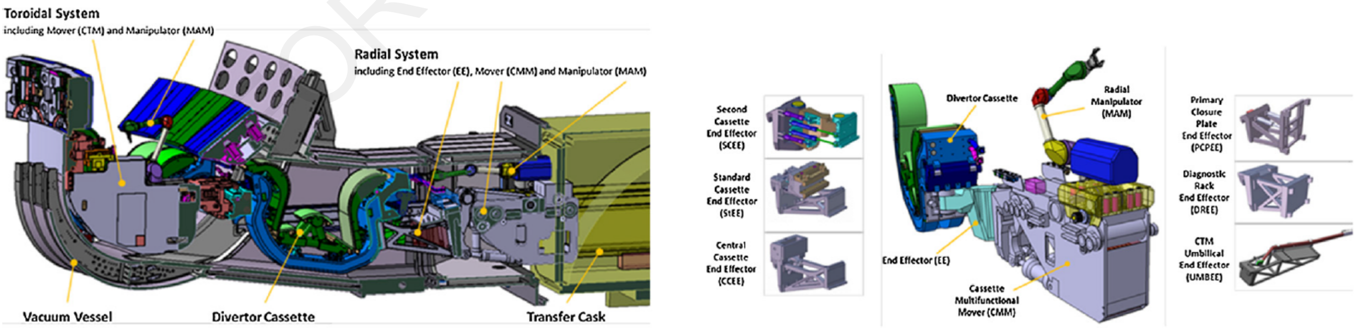


Figure 2: Cassette Multifunctional Mover and interfacing elements

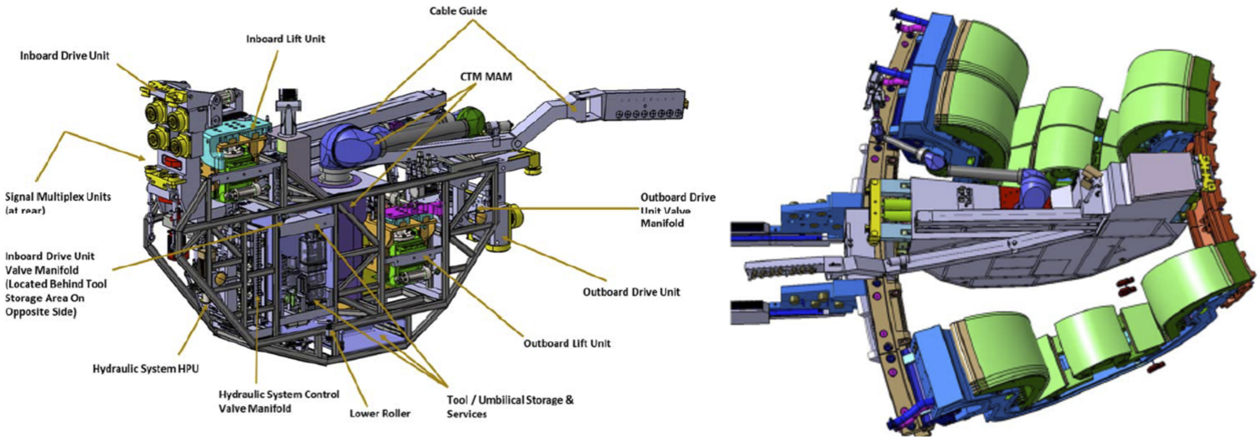


Figure 3: The Cassette Toroidal Mover with covers removed (left) and in the vessel (right)

The DRHS includes two types of remotely operated "movers" which must work together to remove and replace the cassettes. These are:

- The **Cassette Multifunctional Mover (CMM)** (Fig. 2) which can travel along rails mounted in the radial port(s), transport any one of the 54 cassettes, remove or re-install the 1st cassette and then remove or re-install the cassettes to the left and right of the 1st cassette. The CMM must also be able to transport the 2nd mover type, the **Cassette Toroidal Mover (CTM)** (Fig. 3), place it inside the vacuum vessel and remove it on completion of the maintenance activities.
- The **Cassette Toroidal Mover** which, once placed in the vessel by the CMM, must be able to travel toroidally on rails mounted inside the vacuum vessel to reach all the other cassettes (7 on the left and 8 on the right of the entry port) to remove or re-install them. Right (CTM-R) and left (CTM-L) handed variants of the CTM are required for operation on their respective side of the port. The cassettes must be delivered to, or received from, the CMM as required.

Three movers are used in the DRHS, one CTM-R, one CTM-L and one CMM.

The main operations involved in cassette removal, for both CMM and CTM, are:

- disconnection of cassette diagnostics
- cooling pipe cutting
- release of cassette pre-load
- cassette unlocking
- cantilever transportation (as there is no space beneath the cassette to insert a carriage).

The main operations involved in cassette installation, for both CMM and CTM, are:

- cantilever transportation and positioning
- cassette pre-loading
- cassette locking
- cooling pipe welding (and NDT)
- connection of cassette diagnostics

The positional accuracy required to deliver, or collect, a cassette is <5mm. Each mover is equipped with a force feedback manipulator arm, tooling, cameras and sensors. Due to their operating environment, in which activated dust may be present, the movers must be adapted as follows:

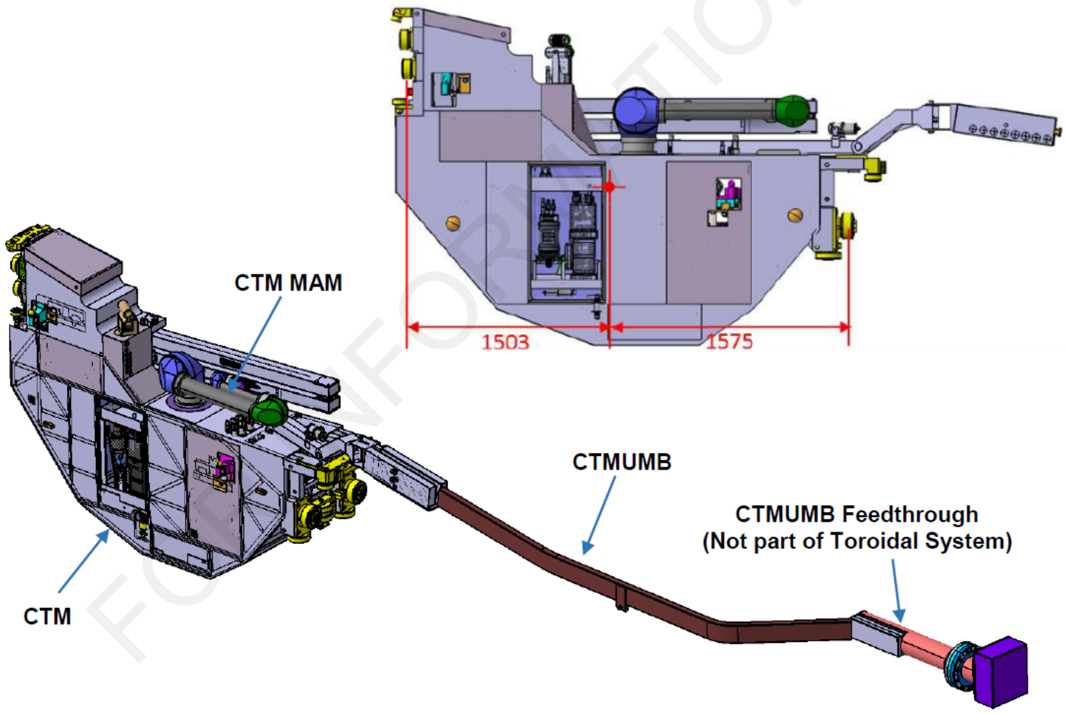
- All components must be radiation resistant in the range of 1-MGy. This can be demanding for electrical and control system components. Accordingly, specific manipulator arms, multiplexers, cameras, etc, must be used.

- Chassis and covers must be constructed from stainless steel. The covers must be designed to prevent the ingress of any dust which may be present in the vessel. Furthermore, they must be designed with smooth outer surfaces to allow easy cleaning (i.e. decontamination).
- The release of oil into the reaction vessel is not permitted. A water based hydraulic system has therefore been specified. Double bearing seals and/or dry radiation hard lubricants must also be selected to meet this requirement.

2. Electromechanical sub-systems

3.1 Movers

The description below is focused on the CTM but is also representative of CMM technologies.

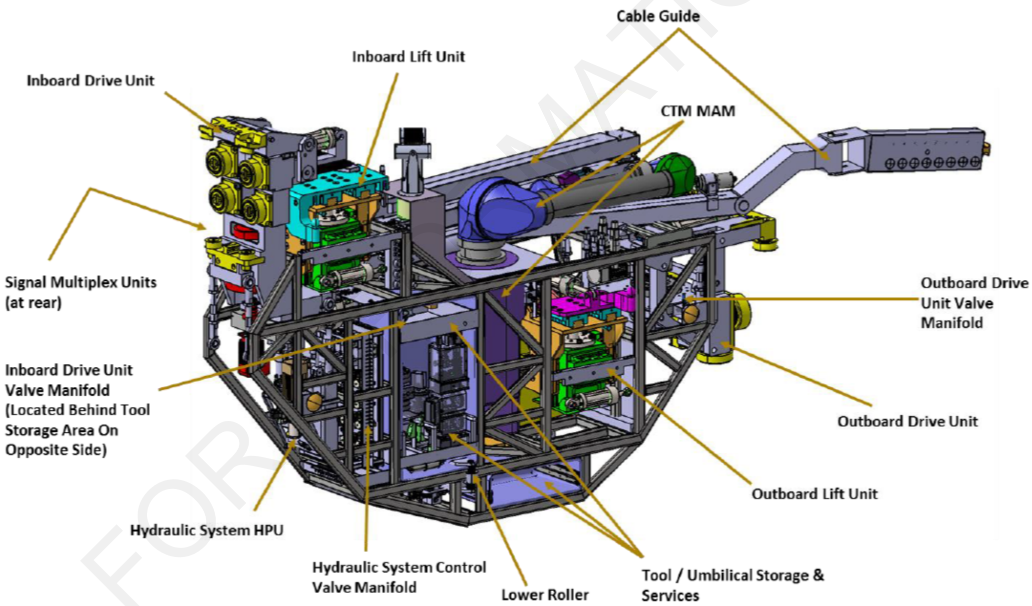


Each CTM will comprise:

- Removeable stainless steel covers to prevent the ingress of dust from the environment, equipped with flexible seals or gaiters as required. The covers are also to protect against escape of internal grease or hydraulic fluid to the vacuum vessel.
- Tubular welded and machined stainless steel chassis to support and locate all sub-systems.
- Retractable cable guide. An articulated stainless-steel conduit carrying electrical power and services to the CTM. To interface with the umbilical (UMB).
- Inboard and Outboard drive units to support and guide the CTM along curved rails fitted within the vessel (NB: the rails are out of scope for this procurement). The drive units include supporting rollers, water based hydraulic cylinders for clamping to the rails during installation, electric motors, planetary gearboxes, resolvers, limit switches, etc.

- Inboard and Outboard lift units with hooks to engage with, and lift, divertor cassettes. 100mm hook travel in each (XYZ) axis effected using linear guides and actuated using water based hydraulic cylinders. Includes LVDT and other sensors.
- Radiation tolerant, electrically powered, Commercial Of The Shelf (COTS) manipulator arm with specific improvements for this application.
- Water hydraulic system to power cylinders in the drive and lift units. The hydraulic system will also power the pre-loading jack tool. Flow modulation via digital valves which are developed for this application.
- Radiation tolerant multiplexing units for the control system, which are developed for this application.
- Radiation tolerant viewing cameras, which are developed for this application.
- Tool and umbilical Storage. Storage of tools and, where required, umbilical to carry electrical power and services.
- The CTM UMB comprises a stainless-steel conduit carrying power and services from the outside of the vacuum vessel to the CTM and will be equipped with electrical connectors at both ends.

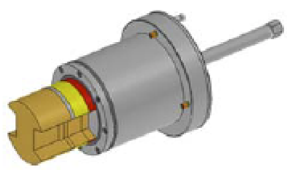
With reference to the above figures, it must be noted that the “CTMUMB Feedthrough” is outside the scope of the DRHS.



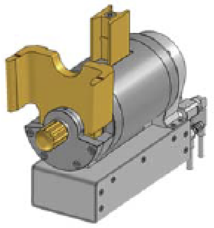
3.2 Tooling

This will include:

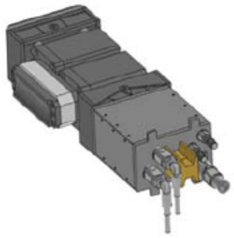
- Pin locking tool (to lock the divertor cassette to, and release it from, the reaction vessel). Mechanical component in stainless steel.



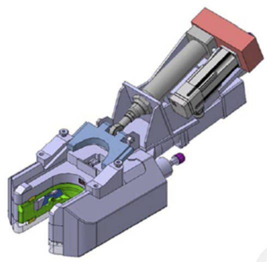
- Wrench tool (to rotate the divertor cassette knuckle). Low speed, high torque electrically powered tool. Stainless steel construction.



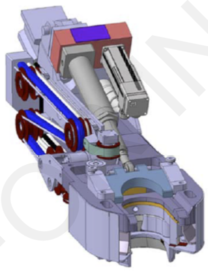
- Hydraulic pre-load jack (to pre-load the cassette in the reaction vessel). Powered by the onboard water based hydraulic system.



- Electrically operated pipe cutting tool (to dry cut the cassette cooling pipes), Stainless steel chassis.



- Automatic pipe welding tool (to weld the cassette cooling pipes). Electrically powered, TIG process. Stainless steel chassis.



- Camera tool. Using radiation tolerant camera as that onboard the CTM.

3. Remote Handling Control System

Each sub-system within the DRHS will be operated independently. However, all will be operated and monitored via a common control system platform, named the **DRHS Remote Handling Control System (RHCS)**. The need for standardization and consistency across the different ITER Remote Handling (RH) systems, and the applicable regulatory criteria of the final installation, mandate the use of a control system, including software, developed specifically for the purpose. The RHCS architecture is as described below:

- The **Low-Level Control System (LLCS)**, which comprises:
  - “GENROBOT” control software. This implements the generic RH controller functionalities, runs on an industrial computer and interfaces to HLCS applications and to cubicles components over EtherCAT. GENROBOT is highly configurable and adaptable to any RH application.

- Cubicles, which include the controllers for the DRHS movers (i.e. control computers with dedicated “GENROBOT” control software), controllers for the BiSS-based multiplexing units for signals and actuators and controllers for the cameras.
- Cables for power and signals from cubicles to the RH devices complemented by connectors, feedthroughs and switching boxes.
- The LLCS includes the electrical system and instrumentation on board the movers.

➢ The **High-Level Control System (HCLS)** which provides the following set of operator interfaces:

- Command and Control (C&C). This is the primary operator Graphical User Interface (GUI) to remotely control and monitor RH devices. The C&C is interfaced to a Joystick for manually driven motion.
- Master Haptic Arm (MA). This is to remotely operate the Manipulator Arm on board the mover. It includes force feedback.
- Operation Management System (OMS). This is to manage, step by step, the operational sequence of RH tasks. OMS provides GUIs for building, executing and analysing RH tasks, and interfaces to the C&C issuing and monitoring operational steps.
- Remote Diagnostic System (RDS). This enables the remote monitoring of the equipment health status to detect degradation, anticipate and diagnose failures through diagnostics and condition monitoring algorithms.
- Virtual Reality (VR). This is to monitor, in real-time and in a 3D graphical environment with augmented reality, the RH equipment in operations. The VR enables the anticipated detection of collision and complements the Viewing System because of the reduced number of camera views in the RH environment.
- Viewing System (VS). This is to display camera views on the monitor displays of the RH work cell.
- The RH Emergency Stop buttons and remote I/O (E-Stop), configured by the ITER RH Supervisory Control System, to set RH devices in a safe state.

➢ The **RH networks** to connect HLCS applications to LLCS controllers using:

- RH Control and Diagnostic Network (RHCDN): implementing a DDS-based command-reply and data monitoring protocol for C&C, RDA, VR and RH controllers.
- RH Real-Time Network (RH-RTN): to establish a real-time connection between the MA and the MAM.
- Audio-Video Network (AVN): to transfer over IP camera video streams from cameras controllers to monitor displays.

It should be noted that the RH networks are outside the scope of the DRHS.

4. Technology Developments and Status

Radiation Tolerant Hardware

The operational environment of the DRHS demands the use of radiation tolerant components. F4E owns a database of COTS components suitable for use in this environment. Components to be used on the movers will be chosen from this list. The supplier will not be expected to undertake the qualification of components resistance to radiation.

F4E has initiated the development of the following items where no suitable COTS component exists:

- Radiation tolerant BiSS based multiplexer.
- Digital Valves for the water hydraulic system
- Radiation tolerant cameras

In addition, a radiation tolerant manipulator arm, to be tailored to this application, has been selected.

Control System

The Command & Control system and "GENROBOT" are ready for use. The (COTS) Master Arm and E-Stop technology to be integrated with these items have been selected. The development of all other specific software is underway.

5. Machine 1st Assembly

It is planned to use simplified versions of the DRHS Movers (CTM & CMM) to assist with the Machine 1st Assembly. Operating conditions will differ from those for Machine Maintenance as follows:

- Operator presence will be possible.
- No radiation
- Ambient temperature will be limited to approximately 30 °C.

These conditions will allow partially functional DRHS Movers to be used. In particular, tooling designed for fully remote operations will not be essential.

6.1 CTM Operating Tasks for 1st Assembly

For Machine 1st Assembly the main functions of the CTM will be limited to:

- Cassette lifting/handling
- Cassette transportation

Other tasks are planned to be performed by operators with manual tooling.

6.2 CTM Sub-Systems for 1st Assembly

The key onboard sub-systems needed for 1st Assembly will be:

- Inboard and Outboard Lift Units
- Hydraulic Power Unit
- Inboard and Outboard Drive Units & Clamps
- 1st Assembly Cable Guide
- 1st Assembly CTM Chassis

6.3 CTM RH Tooling for 1st Assembly

Tooling used for 1st Assembly could be either:

- Specific tooling for manual operation
  or
- Remote Handling tooling deployed by manual operators

The Remote Handling Tooling for 1st Assembly which could be used for 1st Assembly is:

- Pre-Loading Jack Tool (with hydraulic power provided by a stand-alone manual pump)
- Pipe Welding Tool (with services supplied independently)

- Pipe Facing Tool (with services supplied independently)

In this instance the Remote Handling Tooling would be deployed by operators assisted by weight compensation devices.

6.4 CTM Control System for 1st Assembly

For Machine 1st Assembly the CTM control system may be fully independent. In particular, control stations may be located in the Port Cell, local cabling and safety systems may be used and control system software may be specific to the CTM (in this case there would be no need to integrate with any other system). However, this is pending the outcome of current work.

6.5 CTM Safety Requirements for 1st Assembly

The combined presence of both operators and machines during the Machine 1st Assembly phase will require that particular attention is paid to operator safety. Safety features, additional to those required for the final configuration for Machine Maintenance (i.e. fully remote operation), will be necessary in order to achieve compliance with the Machinery Directive.
CE marking of the CTM, related hardware, control and safety systems for Machine 1st Assembly will be necessary.