Fusion Engineering and Design 153 (2020) 111485

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Remote handling strategy and prototype tooling of the ITER vacuum vessel pressure suppression system bleed line valve assembly and rupture disk assembly

Keelan Keogh[a,*], Chang-Hwan Choi[b], David Cooper[a], Steven Craig[a], David Hamilton[b], Stewart Hockley[a], James Kent[a], Chris Lamb[a], Nikola Petkov[a], Andrew Robbins[c], Paul Talbot[a]

[a] UKAEA, Culham Science Centre, Oxfordshire, OX14 3DB, UK
[b] ITER Organization, Route De Vinon-sur-Verdon, CS 90 046, 13067, St. Paul Lez Durance Cedex, France
[c] Assystem 1, The Brooms, Emersons Green, Bristol, BS16 7FD, UK

ARTICLE INFO

Keywords:
Remote handling
ITER
Maintenance
Vacuum vessel pressure suppression system

ABSTRACT

As part of the development work performed under the ITER Robotic Test Facility (IRTF) program, development and substantiation of the maintenance strategy for the Vacuum Vessel Pressure Suppression System (VVPSS) must be investigated. The VVPSS is a key safety aspect of the vacuum vessel of ITER. It ensures that after a coolant leak, and subsequent pressure event, the vessel is protected from the expanding gasses by controlling and venting them appropriately. After an Ingress of Coolant Event (ICE), or during maintenance, the bleed line valve and rupture disk assemblies will require removal and replacement. During removal the confinement function of vessel must be retained. The remote handling of these components while maintaining the first confinement boundary is challenging due to the access restrictions around the pipe flange and environmental conditions in the area. To understand and develop the remote handling strategy for ITER, prototype tooling a mock-up environment has been created. This allows development and confidence in the proposed maintenance strategy leading to the final solution for use at ITER. In this paper we will discuss the prototype tests, the strategies and challenges which need to be overcome for the ITER application, and design considerations that must be taken to future designs to achieve a feasible solution for ITER.

1. Introduction

As part of the ITER remote maintenance strategy development several key technologies have been identified for prototyping as there is no precedence for maintenance of this type. A significant proportion of this work is under collaborative development at the ITER Robotic Test Facility (IRTF) at the UKAEA's RACE facility.

One of the identified maintenance activities required for ITER is the replacement of the pressure relief assemblies for the Vacuum Vessel Pressure Suppression System (VVPSS). There are two sets of pressure relief assemblies in the VVPSS system, one a DN 500 pipe diameter Rupture Disc Assembly (RDA) and a smaller DN 300 Bleed Line Valve Assembly (BLVA). The main function of these is a passive function providing protection from Ingress of Coolant Events (ICE) using rupture disks [1]. In the unlikely occurrence of such an ICE event, these pressure relief assemblies allow direct connection of the vacuum vessel to four vapor suppression tanks (VST) in the Drain Tank Room (DTR). Three of these VSTs are designed for severe events using the DN 500 pipes to release the pressure, the fourth tank is used with the BLVA for less significant events.

These pressure relief assemblies will require replacement in the case of an ICE event or during regular maintenance of the assemblies after 5 years. These assembles are positioned between the ITER neutral beams (Fig. 1) and will be subjected to radiation levels which prohibits human access. The assemblies can be removed for replacement by separating flanges at both sides of the burst disk assemblies as seen in Fig. 2. Once the flanges have been released the assembly can be extracted with a vertical lift.

As the area radiation levels are expected to be ~1 Gy/h [2], too extreme for human access, this results in the requirement for remote tooling to be deployed to perform this flange separation and lift while keeping the internal confinement of the pipeline as these connect directly to the vacuum vessel. During normal maintenance operation, although dust contamination inside the RDA and BLVA is not expected

* Corresponding author.
E-mail address: keelan.keogh@ukaea.uk (K. Keogh).

https://doi.org/10.1016/j.fusengdes.2020.111485
Received 13 September 2019; Accepted 11 January 2020

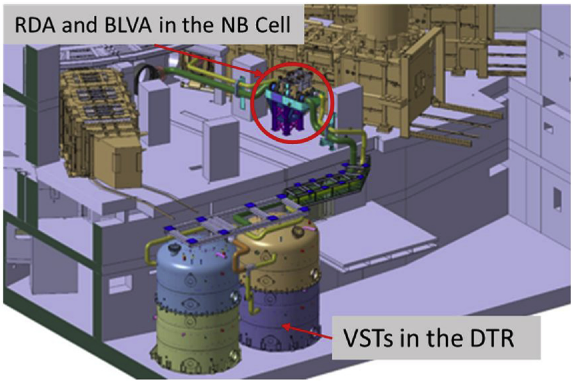

Fig. 1. VVPSS position.

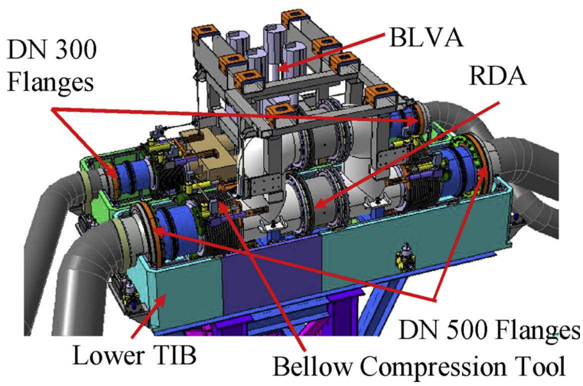

Fig. 2. Flanges and pressure relief assemblies.

to be significant, confinement of the vacuum vessel shall be ensured. After accidental ICE events, it is likely that the components themselves are contaminated. It is required to keep confinement of the RDA and BLVA to prevent the spread of contamination in the NB cell during transportation of these assemblies.

2. Concept designs

The maintenance concept for the VVPSS pressure relief assemblies uses the Neutral Beam Remote Handling System (NBRHS) [2] to maintain the VVPSS. The functions that are defined for this maintenance operation are:

1 Unbolt flanges to the pressure relief assembles
2 Retain confinement of the VVPSS lines
3 Prevent contamination during transport
4 Lift the pressure relief assemblies vertically for extraction
5 The installation of new pressure relief assemblies

To achieve these functions the NBRHS needs additional tooling to perform this task. A Flange Bolting Tool (FBT) is required to perform function 1, and a Confinement Tool (CT) with deployable closure plates are required to achieve functions 2 and 3. The NBRHS will perform the vertical lift and extraction of the disk assemblies achieving function 4. This strategy moves away from previous strategies of remote handling used on JET, where the tooling is normally operated and driven by the MASCOT system. The complexity and scale required for this maintenance strategy results in tooling, which once deployed by the NBRHS act independently of the rest of the remote handling system.

2.1. Flange bolting tool (FBT)

The FBT concept seen in Fig. 3, will be used to bolt and unbolt the flanges. The strategy is the FBT is lowered onto the pipe from a vertical position by the NBRHS, it engages with a permanently positioned rail system on the pipes. These rails provide a datum position and guidance for the tooling to rotate around the pipe axis. The lower arms actuate, closing the arms around the pipe. The FBT offers up an industrial bolt runner to engage with the bolts and provide the bolting/unbolting torque. The concept has two bolt running tools providing redundancy and reducing overall duration of the process. Once the nut runner has unbolted a bolt the entire FBT rotates around the axis of the pipe, on the pipe rail system to engage with the next bolt.

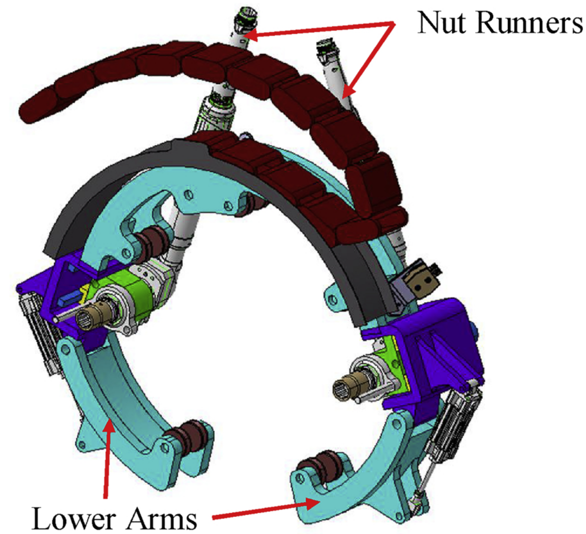

Fig. 3. Flange Bolting Tool (FBT) concept.

Once the FBT tool has unbolted all of the flange bolts, it returns to the vertical position so it can be collected by the NBRHS. The NBRHS will engage to a lifting interface on the FBT, the FBT will release its lower arms and the entire tool can be lifted vertically away from the now unbolted flange. The flange confinement will remain constant as there will be a compressive load on the flange from the bellows assembly next to the pressure relief assembly.

This bolting sequence relies on accurate positioning of the FBT and precise engagement of the nut runners onto the bolt heads. The bolt heads must be retained in position on the flange and the design of the FBT must accommodate the droop of the individual bolts. The cable management of the tool must be considered during rotation of the entire FBT to ensure the tool can operate in all positions on the pipe axis. As seen in Fig. 2 the flanges are also enclosed inside the thermal insulation boxes (TIB). Only the Lower TIBs are shown in Fig. 2 as the configuration is assuming that the upper TIBs are removed to access the RDA and BLVA. This Lower TIB limits the access to the underside of the pipe flange and constrains the design of the tool concept.

2.2. Confinement tool (CT)

The CT acts in a similar fashion to a deployable glovebox. As seen in Fig. 4, most of the tool is a large enclosure with an internal manipulator. Below the box there is a clamshell assembly. When the CT is lowered onto the pipe flange by the NBRHS, the clamshell assembly goes around the pipe flange. The clamshell has two lower arms which close around the circumference of the flange creating a seal. Once sealed the faces can be retracted, by using a bellows compression system which is connected to the bellows. This allows the flange faces to be separated by 150 mm.

Once the flanges are separated confinement is still retained by the CT, an internal hatch opens connecting the inside of the CT confinement box with the VVPSS line. This allows access for the internal manipulator to enter through the hatch between the two flange faces.

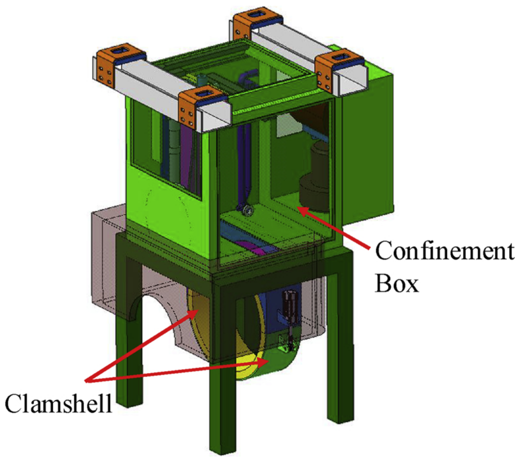

Fig. 4. Confinement Tool (CT) concept.

The CT will then perform a cleaning and inspection activity of the flange faces and inside the pipeline. Once clean the CT will deploy closure plates into each of the pipes sealing both pipe ends. This allows the CT to be removed and confinement of each end of the pipe to be retained. With confinement on both flanges on either side of the pressure relief assembly, it can be removed for replacement.

To maintain confinement the tooling must remain sealed with manipulation inside a confinement barrier. This creates the challenge of the CT confinement box complying with appropriate requirements of in vessel remote handling. The manipulation must also be self-contained, with all required components inside the confinement boundary. This results in a large tool to perform this task this can be seen in Fig. 5. During the sealing of the clamshell a flexible sealing material is needed to compress against the flange. An appropriate sealing material will need to be identified to work with vessel consideration, but a suitable foam has been identified for the trials.

3. Detailed design

To understand the challenges of such a complicated operation,

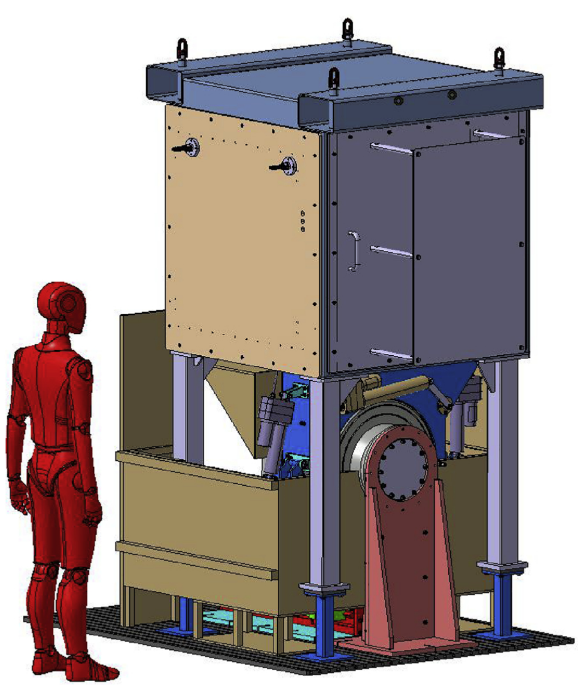

Fig. 5. CT positioned on Mock-Up Environment.

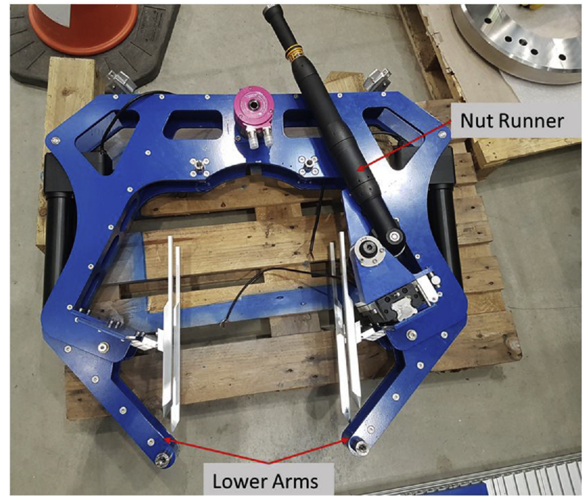

Fig. 6. Prototype FBT at the RACE facility, Culham.

prototype tooling has been created to test the full operation of this maintenance activity. An Operations Sequence Description (OSD) has been created based on the concept of the tooling. The prototype tooling will inform and develop this OSD for the activity. The prototype is focused on the remote handling functional activities, demonstrating the feasibility and identifying areas requiring improvement.

3.1. Flange bolting tool

The prototype FBT (Fig. 6) was developed by RACE. This prototype is designed to represent the functionality of the device required for ITER, but concessions have been made in the assembly to increase modularity to allow flexibility in the tool development and in the use of non rad hard components in the assembly. The modularity allows testing of individual aspects of the tooling prior to full assembly tests.

The full operation tests will highlight improvements needed to the design to allow the tooling to operate. Cable management of the tooling during the rotation has been identified as a challenging area for the design and will need to be investigated further. Further tests are required to understand the FBT interaction with other aspects of the design.

3.2. Confinement tool

The CT was assembled and tested in two parts. The framework structure as seen in Fig. 7 shows the clamshell and closure plate in its parked position. The bulk of the development work has been done on the XYZ manipulator mounted on a vertical tool block as seen in Fig. 8. The design has been made modular based on the functions concept design. This allows the various aspects of the prototype to be tested in isolation during the development trials.

Due to the complexity of the CT operations the CT can be broken into six individual sub-assemblies which were identified using a functional breakdown structure (FBS). These are;

- Framework structure (creates the confinement main body and alignment of the tool)
- XYZ manipulator (Positions plates, inspection system, and vacuum nozzles)
- End Effector (holds vacuum nozzle, inspection system, and closure plates)
- Closure plate (provides sealing function of the VVPSS pipeline)
- Closure plate park (securely holds closure plate)
- Clamshell (creates confinement around flange)

Fig. 7. Prototype CT at the RACE facility, Culham.

Fig. 8. XYZ test rig at the RACE facility, Culham.

The XYZ manipulator provides complex compound motions of the end-effector to clean the internal features of the flange and pipe. To develop this control the XYZ is being tested mounted separately from the rest of the CT to allow unrestricted motion of all its axis.

The CT for ITER will be functionally akin to the prototype design but will require some modifications. The main framework will be different than needed in the ITER application. The framework structure of the prototype design has been identified as challenging for decontaminate due to the internal structure of the CT box. The ITER tool will have to consider designs similar to a glovebox. This would be a welded stainless-steel structure with curved edges for cleaning. This deviation does not impact the remote handling functions so is permitted.

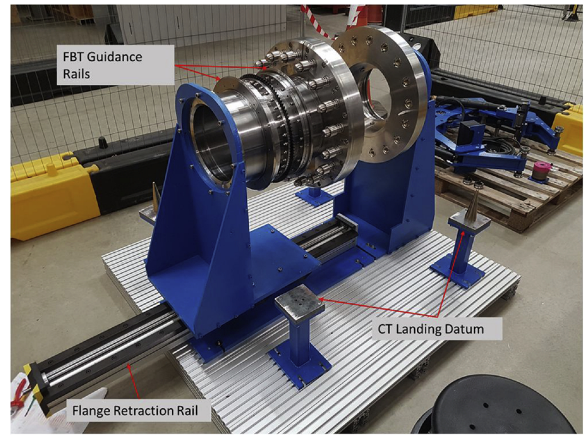

Fig. 9. Mock-Up Environment.

3.3. Mock-up environment

The Mock-up Environment (Fig. 9) is designed to replicate the arrangement and flange design expected on either side of the BLVA. The Mock-Up has 18 pop-up bolts. The design is based on remote handling principles [3] these bolts are in a flange for the DN300 pipeline. There is a permanent rack and rail system on the pipe to interface with the FBT. There are four landing pads around the flange to align with the CT legs providing a datum position for the clamshell over the flange.

4. High level operations sequence description

The maintenance strategy for the VVPSS tooling has been detailed in preparation for use at ITER, the development of the prototype tooling will highlight any development areas for this OSD. The OSD will be used as instruction for the operators of the ITER maintenance when it is required. The high level OSD can be described as:

1 Collection of the Flange Bolting Tool
2 Pre-loading of the flange with the bellow retraction system
3 Deployment of the Flange Bolting Tool
4 Operation of the Flange Bolting Tool
5 Removal of the Flange Bolting Tool
6 Parking of the Flange Bolting Tool
7 Collection of the flange Confinement Tool
8 Deployment of the flange Confinement Tool
9 Separation of the flanges
10 Operation of the flange Confinement Tool
11 Removal of the flange Confinement Tool
12 Parking of the flange Confinement Tool

The areas of detail are item 4 the operation of the Flange Bolting Tool and item 11 the operation of the Confinement Tool.

4.1. Operation of the FBT

During the operation of the FBT it will operate in a semi-automated fashion with supervision by the remote handling operators. This allows the operators to adjust parameters of the tool in real time to achieve the functions of the tool if needed. The tool will engage with the bolt, untorque a bolt, disengage from the bolt, and move onto the next bolt as a prescribed sequence. The tooling is also used in the installation of a new component but in reverse order.

4.2. Operation of the CT

The CT operation, like the FBT will be automated where practical.

The operator will have camera views inside the enclosure box and on the end-effector, if any adjustments are needed to position, the operator can take control of the motions and complete the tool operation sequence, which are;

1 Opening of Clamshell hatch
2 Cleaning of components
3 Collection and installation of the first closure plate
4 Collection and installation of the second closure plate
5 Closure of clamshell hatch

5. Summary

The VVPSS maintenance has been identified as a challenging remote maintenance activity without precedence in terms of scale or complexity previously used on fusion devices. The concept design has been detailed for prototype tooling to develop the remote handling strategy of these independent operating tools. The tooling has been designed essentially as standalone manipulators, once they are deployed by the NBRHS they operate independently to complete the task. This is a change from the strategy that has been used on JET where the tooling is normally powered directly by the RH system. Various tests have been done on the tooling examining interfacing with the mock-up environment and operation of individual axis movements. This has shown promising results for operations.

The full sequence testing of the VVPSS tooling will be beginning in the final quarter of 2019, this will align with the OSD document. This will prove the; installation and removal of the CT and FBT from the Mock-up Environment, the sealing of the pipes using a remotely deployed closure plate, the ability to position a cleaning tool around the flange face, and developing reliable operation of the tooling.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] A. Pesetti, G. Giambartolomei, et al., Mitigation of a loss of coolant accident in ITER vacuum vessel by means of steam pressure suppression, TECNICA ITALIANA-Italian J. Eng. Sci. 63 (June (2-4)) (2019) 227–234.
[2] C. Damiani, J. Palmer, et al., Overview of the ITER remote maintenance design and of the development activities in Europe, Fusion Eng. Des. 136 (2018) 1117–1124.
[3] S. Mills, A. Loving, Design and Development of RH Tools for the JET Divertor Exchange, SOFT, 1996.