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Factors affecting remote handling productivity during installation of the ITER-like wall at JET

S. Collins*, G. Matthews, J. Thomas, G. Hermon

CCFE EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK

HIGHLIGHTS

- The paper describes the challenges to achieve the installation of the ILW beryllium sliced wall.
- Examines the factual difference between estimated remote handling in-vessel durations and those achieved, with a view to quantifying the typical disparity between the two.
- The paper will elaborate and highlight the contributing factors. This offers an opportunity to provide provenance for availability estimates of devices such as ITER and DEMO.
- The paper will identify and describe the factors influencing the ratio between estimated versus the actual durations for remote handling operations.

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ABSTRACT

Remote handling operations at JET have encountered many challenges to achieve the installation of the ILW beryllium sliced wall during the Enhanced Performance stage 2 (EP2) shutdown of JET. This was a demanding and challenging activity which was based on the experience gained from a period of over 15 years (20,000 h operations) of JET In-Vessel remote handling operations.

This paper describes the difference between estimated remote handling in-vessel durations and those actually achieved with a view to quantifying the typical disparity between them.

There are many factors that affect productivity of the remote handling operations and it is important to accommodate these either in the design of the component or within the production of the operational procedures with a view to minimise all impact on the final task duration.

Some factors that affect the efficiency are outside the control of the design and operational procedures. These are unforeseen anomalies that were encountered during the removal, naked wall survey and installation of the components. Recoveries from these anomalies are extremely challenging and need to be addressed efficiently in order to minimise the impact on the shutdown duration and prevent optimised panned activities from becoming inefficient by fragmentation.

1. Introduction

The EP2 shutdown was developed to allow the JET Torus to operate an ITER like first wall protection configuration as shown in Fig. 1.

The project included the removal of approximately 4000 individual assemblies (existing CFC wall).

After the removal and cleaning of the Vessel approximately 2700 individual assemblies were installed (Be sliced tiles, bulk tungsten and tungsten coated CFC tiles).

The sliced Be design consists of delicate castellated Beryllium tile segments mounted onto an inconel carrier assembly. The tile segments are very sensitive to damage; almost any type of damage would seriously affect the machines operational performance during start-up and into subsequent operational campaigns thus handling techniques needed to be highly developed and controlled.

The design constraints of the tile assemblies meant that the tile fixing bolt access hole could no longer be in the front face of the tile. The design therefore evolved into the use of fixing bolts that were concealed by the next installed assembly. Due to the design constraint of concealed fixing bolts the planning of the installation is more critical due to any installation issues encountered would prevent the installation of the subsequent assemblies.

To protect the ILW Be wall from damage during machine operations it was necessary to install an Embedded Diagnostic System as shown in Fig. 2.

The installation covers almost half the JET Torus. The system connects the diagnostics embedded in the new tiles to the outside via a feed through located in a main vertical port.

* Corresponding author. Tel.: +44 01235 465343.
E-mail address: steve.collins@ccfe.ac.uk (S. Collins).

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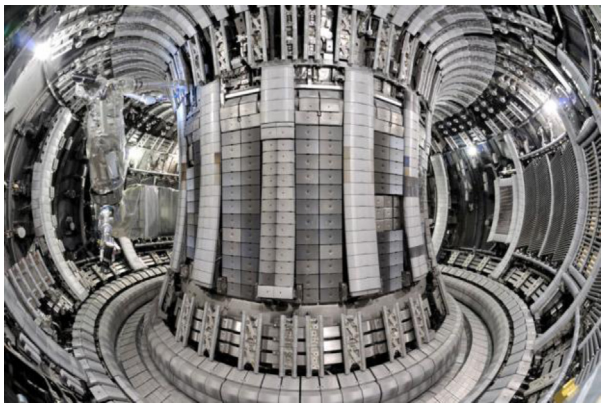

Fig. 1. JET ITER like wall.

The scale and complexity of this project was a significant challenge and many new remote handling techniques were required.

There was a huge variation in the type of components being handled, from 9 m cable looms covering the entire installation to 2 m pre-wired conduits with a mass of over 20 kg. These components numbered 48, with nearly 40 being unique. Handling these components required the design and manufacture of 193 different handling tools. A number of obstructions along the route had to be cut from the wall. 26 new support rails had to be welded to the vessel wall. Accurate surveys of the mounting points and environment were required using remote handling techniques.

2. Planning

The In-Vessel Plan was created in Primavera P3E and derived from an EP2 planning document. It formed the critical path for the entire EP2 Shutdown project and contained approximately 835 activities, totalling 5500 h of effort. The plan was produced based on an 18 h working per day, 7 days per week. 136 additional unplanned activities, totalling 682 h were added in response to unforeseen anomalies encountered during the shutdown. The plan was managed in accordance with a strict quality change control process throughout the Shutdown. Were delays with deliverables occurred, the plan was optimised to maintain the critical path. The plan was monitored daily and progress updated weekly to manage target finish milestones effectively.

Resources were driven from a Primavera P3E plan and constantly optimised in order to meet the shutdown milestones.

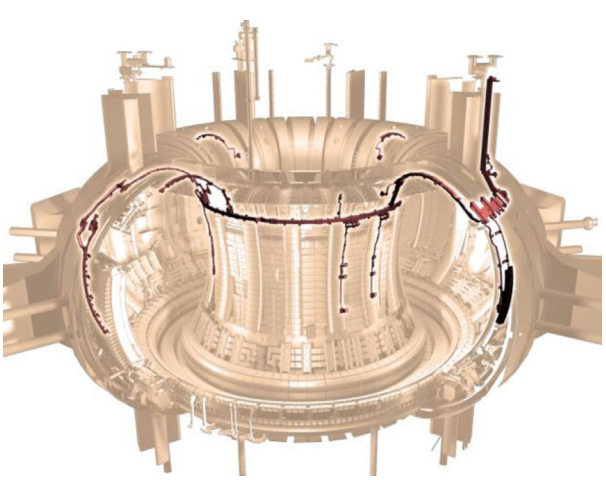

Fig. 2. EP2 diagnostic conduit route.

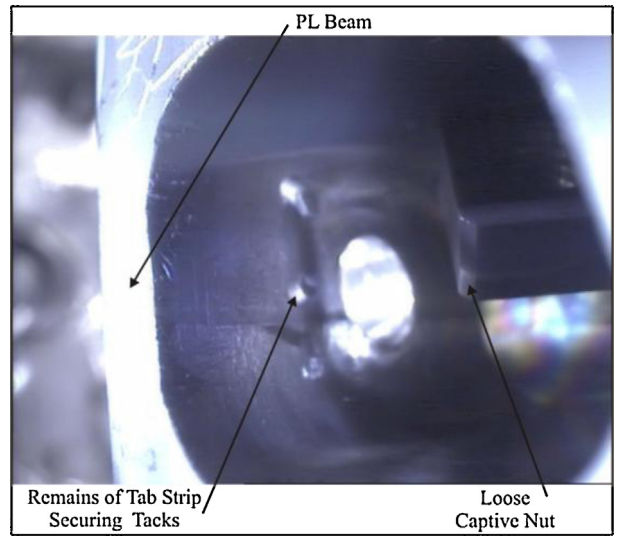

Fig. 3. Image showing loose captive nut in PL beam.

3. Remote handling systems availability

Maintenance of the R/H equipment during the EP2 shutdown was based on a 10 h period after approximately 224 h of In-Vessel operations. This is the optimal duration and is based on the data accrued from over 20,000 h of remote handling operations within the JET Tokomak.

Utilizing this maintenance regime allowed remote handling operations to achieve a Mean time between failures (MTBF) of 65.4 h and a mean time to recovery (MTTR) of 2.4 h. This data is based on the results accumulated throughout the EP2.

The low MTTR is achievable because the remote handling equipment has a short duration to extract the system to a location that it can be worked on manually. This duration would be greatly increased if the system required a long recovery time/process and also if the repair work was to be carried out using remote operations.

4. Anomalies

Anomalies were identified and encountered during the strip-out of the CFC tiles, survey of the wall, vacuum cleaning of the Vessel structure and also during the installation of new ILW tile assemblies/diagnostic. During the EP2 shutdown 227 anomalies were logged whilst undertaking the remote In-Vessel activities. Below are a few examples of the typical anomalies that were encountered.

4.1. Anomaly report no. 28

During the removal of the Poloidal limiter modules from PL 4b it was found that the module tooling would not engage in the captive nut within the beam. On further investigation it was found that the bolt length in the tooling was of the correct length and should have engaged. This suggests that the cage nut that is located in a machined pocket within the beam and retained via a locking shim may be loose within the pocket or even not captivated as shown in Fig. 3.

Investigation of report: – An inspection of the effected area was carried out and it was found that the captive nut was not captivated within the pocket and was loose within the bottom of the pocket.

Remediation: – The loose nut was recovered using the remote handling system. A new design of captive nut was designed and

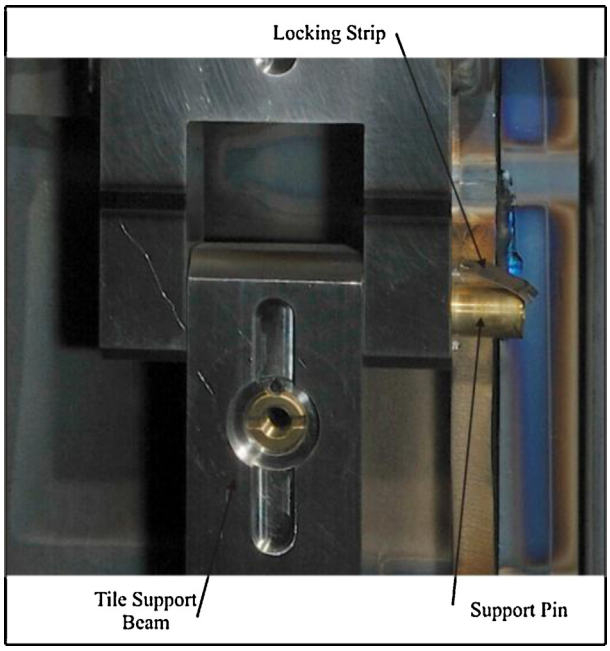

Fig. 4. Loose inner wall cladding hinge pin.

remotely installed before the installation of the ILW PL tile carriers at this location.

4.2. Anomaly report no. 68

The hinge pin at the top of the inner wall cladding beam has worked loose during machine operations and found to be protruding from the side of the beam. The tab strip used to secure the pin within the beam had broken allowing the pin to slide out during machine operations shown in Fig. 4.

Investigation of report: – An inspection was carried out at all of the other locations that the pin was used and the fault was present in a number of other locations. Analysis was carried out on the locking strip and concluded that the locking strip requires upgrading (Fig. 5).

Remediation: – All of the pins were pressed back into the beams and the locking strips replaced with an upgraded strip (Fig. 6).

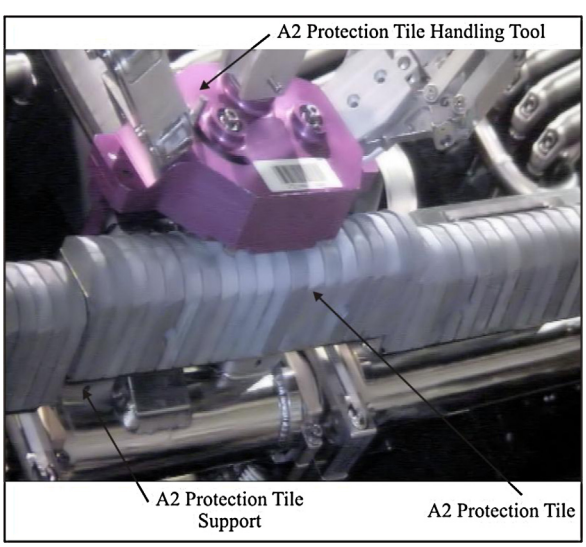

Fig. 5. Sliced Be A2 protection tile.

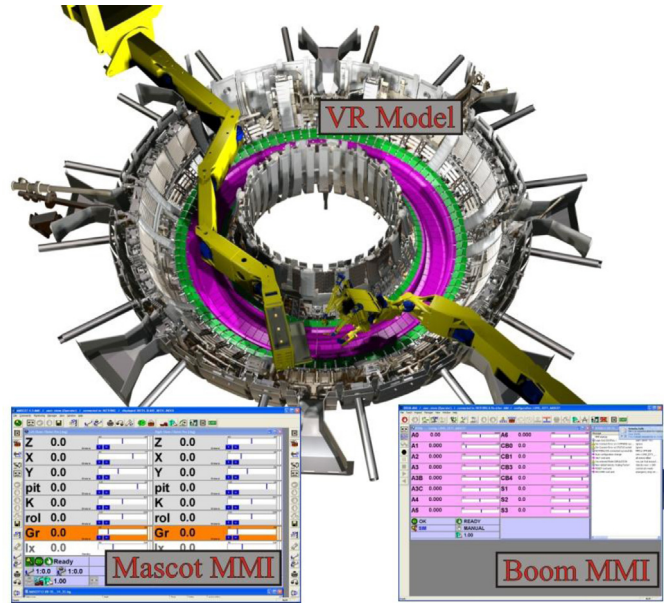

Fig. 6. VR model.

4.3. Anomaly report no. 193

A2 Tile on Antenna 5/6 Position 8 (Middle Bottom) will not engage into both keyholes. Pitch error suspected as individually each end of the tile will engage but when tried together installation can not be achieved.

Investigation of report: – An assessment was carried out and it was found that the new tile design was less compliant to a pitch error between the two mounting points than what the original tile design is. The error in the pitch of the mounting supports had originated from previous manual welding of support plates onto the A2 protection tile support rail.

Remediation: – The affected tiles were removed from the Vessel and the design modified to comply with discrepancy between the two mounting points.

5. Estimation of remote handling durations

Remote handling In-Vessel durations are estimated using a number of tools. These include:

5.1. Run-throughs in the virtual reality environment

moving the articulated Boom and Mascot model real-time with a direct link from the MMI's (Man Machine Interface).

5.2. Full scale mock-ups

are used for new and challenging activities that require a better understanding of the complexity of the component manipulation. These are usually carried out in the full scale mock-up facility using the real systems.

5.3. Basic estimation duration

is achieved by breaking the activity down into small tasks and calculating an overall estimate for the duration.

The estimated duration above is then evaluated using the 15 years and 20,000+ hours of In-Vessel remote handling operations experience to determine a realistic estimation of these cycle times consistent with the actual duration achievable.

5.4. Objectives

Reliable, accurate and achievable durations are essential for the successful planning of any remote handling operations. The vast experience that has been gained in remote handling within the JET vessel enables a detailed evaluation of this data to be carried out.

For the purposes of this paper two EP2 Shutdown tasks are analysed and the basic estimated durations compared with the actual durations achieved. The tasks are: Installation of ILW Poloidal limiter tile carriers and the installation of inner wall protection tiles. The objective is to establish the ratio between the basic estimated verses the actual durations for remote handling In-Vessel operations, enabling the output to be used to calculate future estimations and providing more accurate planning data.

5.5. ILW poloidal limiter tile carriers

Basic estimated installation duration (as described in Section 5.3 above) was calculated for an ILW Poloidal Limiter tile carrier and this equated to an installation duration of 14.5 min per tile carrier. This basic study was evaluated and adjusted using the remote handling experience gained at JET to ascertain a more consistent duration with that actually achievable. An estimated duration of 30 min per carrier was used for the P3e plan.

Analysis was carried out on the installation of 100 ILW PL Tile Carriers during the JET EP2 Shutdown and an actual mean time installation of 34 min per tile carrier was calculated.

The table and chart below (Fig. 7) shows the average installation time for four different PL beams each with 25 tile carriers per beam.

Beam ID	Start date	Total time	Average time (25 carriers)
PL6B	21/10/2010	19:12	00:46
PL6D	24/10/2010	14:29	00:34
PL5D	14/03/2011	12:02	00:28
PL4B	22/03/2011	11:24	00:27

5.6. Inner wall protection tiles

Basic estimated installation duration (as described in Section 5.3) was calculated for an IWGL tile and this equated to installation duration of 7 min per tile. This basic estimate was evaluated and adjusted using the remote handling experience as described in the PL Tiles above and an estimated duration of 15 min per carrier was used for the P3e plan. Analysis was carried out for the installation of 4 random tiles during the JET EP2 Shutdown and an actual mean time of 17.7 min was calculated.

The table below shows actual installation durations.

Date	11/04/2011	31/03/2011	31/03/2011	31/03/2011
Task ID	TIL_013_18	TIL_013_17	TIL_013_17	TIL_013_17
Tile ID	524	242	244	245
Duration	22.25 min	17.5 min	18.5 min	12.5 min
Video ID	Disk no. 5	Disk no. 5	Disk no. 5	Disk no. 5

The data above provides a ratio between the basic estimated and actual durations as shown below:

- ILW PL tile carries = 2.3:1.
- Inner wall protection tiles = 2.5:1.

Some of the factors for the differential are:

(1) Reading and absorbing the operational procedures, once absorbed and understood these actions need to be portrayed to the appropriate operators within the team. Generally it is found that the higher the complexity of the procedure the greater the impact on the duration.
(2) Once the remote handling system has been deployed to the work face the orientation of the camera views must be corrected for the servo manipulator operator. Failure to correctly orientate and provide the best possible views will result in very poor productivity from the manipulator operator as the quality of the views are paramount for the operator to successfully and efficiently complete the task.
(3) Operational process failures. A number of problems were encountered during the installation of the above tiles, these ranged from tile fixing bolt drive key becoming stuck in the head of the fixing bolt, Tile orientation to be changed after collection and a number of logistic issues/anomalies between the configuration component interface and actual interface.
(4) Compromise of the component design. It is not always possible to accommodate all of the remote handling requirements. If requirements are not accommodated into the component then this will ultimately translate into an operational constraint and effect productivity. One example of this is the inner wall protection tiles analysed above. The remote handling requirement

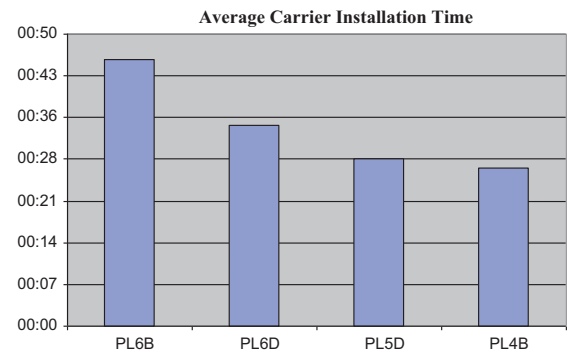

Fig. 7. Average PL tile installation duration.

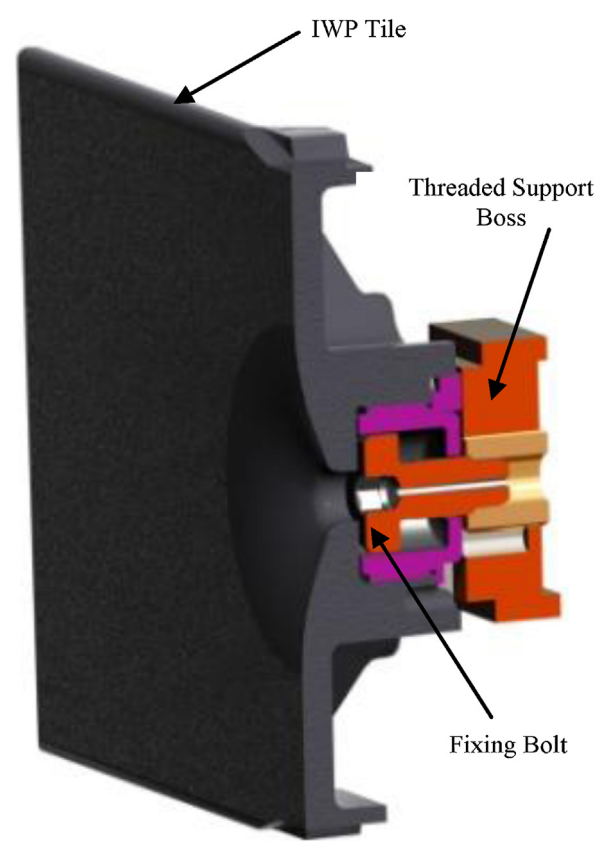

Fig. 8. A section view through an inner wall protection tile and highlights the fixing bolt retracted the tile does not fully engage with the vessel interface.

was for the tile to fully engage onto its location features before the single fixing bolt engaged into the threaded insert on the Vessel wall. It was not possible to easily accommodate this into the design without compromising the performance of the tile. This left the design of the tile prone to cross threading and subsequently required additional In-Vessel operations to resolve (Fig. 8).

6. Conclusion

From the data collated it is clear that the ratio between the estimated and actual duration is dependent on a number of factors, these include: – complexity of the task, frequency that the task is to be undertaken, quality of available views, encountered anomalies and equipment reliability. The historic data that has been accumulated over the past 20,000+ hours of In-Vessel remote handling operation shows that as the complexity of the tasks increase the ratio between the estimated and actual durations is also increased. It is very clear the frequency that the task is carried out also has a dramatic effect on this ratio. To achieve an accurate and reliable estimation of task durations it is necessary to have a good understanding on these influencing factors and accommodate them into these estimations. The knowledge and experience gained by the remote handling unit at JET is beneficial and allows accurate task durations to be estimated.

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