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N. Sykes, S. Collins, A.B. Loving, V. Ricardo, E. Villedieu
and JET EFDA contributors

# Design for High Productivity Remote Handling

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N. Sykes[1], S. Collins[1], A.B. Loving[1], V. Ricardo[1], E. Villedieu[2]
and JET EFDA contributors*

***JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK***

*[1]EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*
*[2]Association Euratom-CEA Cadarache, DSM/IRFM, Saint Paul Les Durance, France*
** See annex of F. Romanelli et al, "Overview of JET Results",*
*(Proc. 22[nd] IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

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**ABSTRACT.**
As the central part of a programme of enhancements in support of ITER, the Joint European Torus (JET) is being equipped with an all-metal wall. This enhancement programme requires the removal and installation of 6,927 tile carriers and tiles, as well as the removal and installation of embedded diagnostics and antennas. The scale of this operation and the necessity to maximise operational availability of the facility added a requirement for high productivity in the remote activities to the existing exigencies of precision, reliability, cleanliness and operational security. This high productivity requirement has been incorporated into the design of the components and associated installation tooling, the design of the installation equipment, the development of installation procedures including the use of a mock-up for optimisation and training.

Consideration of the remote handling installation process is vital during the design of the in vessel components. A number of features to meet the need of the high productivity while maintaining the function requirements have been incorporated into the metal wall components and associated tooling including kinematic design with guidance appropriate for remote operation. The component and tools are designed to guide the attachment of the installation tool, the installation path, and the interlocking with adjacent components without contact between the fragile castellated beryllium of the adjacent tiles. Other incorporated ergonomic features are discussed.

At JET, the remote maintenance is conducted using end effectors, normally bi-lateral force feed back manipulator, mounted on driven, articulated booms. Prior to the current shutdown one long boom was used to conduct the installation and collect and deliver components to the "short" boom[3] which was linked to the tile carrier transfer facility. This led to loss of efficiency during these movements. The adoption of a new remote handling philosophy using 'point of installation' delivery of components via an additional long boom and a sophisticated logistics system based on 'task modules' is described and operational efficiencies detailed. The enabling programs and software behind this new approach needed significant development. Systems such as a task module manager database, image visualisation, virtual reality simulation, operational document system and teach files, which have significantly evolved since their initial inception in 2002, will be elaborated.

## 1. HISTORY AND DEVELOPMENT OF REMOTE HANDLING AT JET.

Since the first utilization of remote handling at JET the extent and complexity of the remote activities has increased from c. 600 components in 20 weeks in the remote tile exchange shutdown 1998 to c.7000 components in a year in EPII. To maintain the value of the facility as an experimental reactor, the ratio of time available for experimental campaigns to the duration of enhancement shutdowns must be maintained high while undertaking this increasingly complex and extensive activity.

## 2. COMPONENT AND TOOLING DESIGN

Figure 1 shows a schematic of the Beryllium Sliced Tiles Carrier that is installed on an inner wall guard limiter beam, in the JET vessel. It contains a number of features that are illustrative of the considerations made in component design to facilitate efficient remote handling. The tiles are installed sequentially from bottom to top on the beam allowing attachment bolts to be occluded from the line of sight of the plasma[4].

During installation the tile carrier is initially placed by eye on the supporting beam, resting on the contact pads, fig.1 item 1, and the location bosses, fig.1 items 3 & 4, above the adjacent tile carrier. The contact pads, ensure that the attitude of the carrier is correct when it engages with the adjacent carrier, averting a clash between the fragile adjacent beryllium tiles. The carrier is then lowered down against the beam, the lead in features fig.1, item 2, on the tile carrier beneath guide the lateral location of the component, so that the dowel location boss and slotted location boss, engage into the location holes in the beam. The slotted locations boss, allow both bosses to engage within their respective holes even though their central axis is not parallel. This engagement can be visually assessed and felt using the force feedback systems of the manipulator at JET, and results in exact kinematic location. The final location of carrier and the approach path ensures that the gaps between tiles on adjacent carriers can be controlled to submillimetre tolerances while ensuring that there was no impact between them during installation.

The bolts are designed to "pop up"[1] so that they are clear of the contact points during installation. They are captivated by threads in the tile carriers or by the attached remote handling tool, preventing loss during installation (see figure 2). The nose of the bolt engages with the female thread squaring the bolt prior to the engagement the mating threads (see figure 3).

The thread is of the bolt is fully feathered. (see figure 4).

The applied torque on these bolts is kept to the minimum force required for the application, this both reduces attachment time but also facilitates future removal. The peak loosening torque, for bolts in the fusion vessel environment, has been empirically found to be twice the installation value. Therefore minimizing the installation torque minimizes the risk of shear in the bolts.

The sum of these measures substantially reduces the propensity of cross threading during bolting procedures.

The tooling attachment bolts fig.5 item 5, are left hand threads which enables the same bolting tooling to be used for both attaching the carrier and detaching the tooling without adjustment of ratchet positions.

The associated tool design is shown in figure 5. The tool is designed in an ergonomic manner with respect to weight distribution and visual access in a remote environment.

The tool design also incorporates defined kinematic engagement, utiliziling the tile to tile location features on the component that allows the operator to feel that the tool is correctly located using the force feedback system, The operator will then proceed to engage the remote handling compatible pop up attachment bolts. The tile tool also incorporates a location to place the attachment tool, fig.5 item 7, minimizing the movement required to collect the tool.

## 3. "POINT OF INSTALLATION" ENABLING EQUIPMENT

As discussed the current system for operation at JET deploys a point of installation approach where the tools and components to be utilized in a particular operation are deployed to place of work of the manipulator, minimizing the time in motion between installation activities. A number of pieces of newly designed equipment were needed in order to fulfill this requirement.

### *3.1 EXTENDED OCTANT 1 BOOM*

The Octant 1 articulated boom [2] was redesigned so that its scope of operation included the full Torus see, figure 7, increasing the number of articulated joints utilized. The strength of the boom was increased to take 550kg at the end, for example this allows the task module, described below, to support around 400 Beryllium coated CFC protection tiles.

### *3.2 TASK MODULES*

Task modules have been designed to transport the components and tools. Their design comprises 6 drawers and a tool box . The drawers are operable by the manipulator, they can be opened on either side of the module to enable either vessel left or right operation. Each drawer can contain a tray which supports the components such as the example below.

### *3.3 VERTICAL TRAVERSE SYSTEM*

The task modules can be remotely collected and docked using the vertical traverse system (see figure 9), maximizing the available components without manned intervention. The vertical traverse section can also remotely collect the "roll end effector", which using an automatic tool exchanger can remotely dock to trays and turntables, which permits the collection of components outside of the size constraints of the task module.

## 4. SUPPORT SOFTWARE SYSTEMS

To support these modifications in equipment a number of software systems have been developed. A database called the "task module manager" tracks the content of the drawers of each task module. The contents are updated as the components and tools are manually loaded into the task modules. This database is able to interface with Operational Document System where the components will be unloaded to the vessel as part of the operational sequence, thus full traceability of the in vessel tools and components is maintained.

The manual loading of the task modules is supported by rapid image generation software which produces realistic diagrams of the required tray loading along side tabulations detailing the identities of required components against there loading locations and any specific guidance from the operational sequence on the handling of the components.

In the development of the operational sequence documents Virtual reality simulations are used to develop and test procedures in advance of their enactment. This enables the operations engineer determine the feasibility and accessibility of a particular operation early in the project lifetime allowing hem to input into the design of tooling and components. This system also allows the engineer to determine the optimum motions of the boom and manipulator in advance of the operations thus reducing time in motion.

This also enables "teach files" to be developed these are pre-programmed movements of the articulated boom and manipulator. These movements can be conducted at higher speed as they have already been identified as safe by the operations engineer. As a further safety precaution a green ghosted image of the completed move is utilized to illustrate the trajectory of the boom and manipulator so that the operators can visually confirm that the there is no risk of collision.

Operational document sequences are prepared in a flow chart style so that proven efficient actions once developed can be repeated and deployed in a number of tasks.

## CONCLUSIONS

The overall effect of the above measures was to increase the productivity of the remote operations. The table below shows the productivity of the same task, removal of Inner Wall Guard Limiter Tiles, which has been undertaken remotely on a number of JET shutdowns using the short boom and in the EPII shutdown with the point of installation enabling equipment.


## ACKNOWLEDGEMENTS

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## REFERENCES


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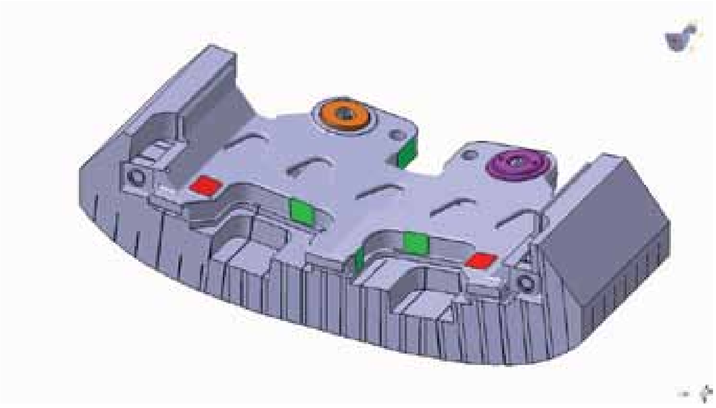
[2]. B. Haist et al. Remote handling preparations for JET EP2 shutdown Proceeding of the 25th Symposium on Fusion Technology

[3]. L. Jones et al., Design and Development of a new transporter facility for JET, Proceedings of the 19th Symposium on Fusion Technology Lisbon (1996).

[4]. G. Matthews et al. Physica Scripta (2007) 1-7


| JET Shut Down | Year | Average removal time per tile |
|---|---|---|
| Remote Tile Exchange | 1198 | 37 |
| Pellet Launcher | 1999 | 42 |
| Septum Replacement Plate | 2001 | 37 |
| EPI | 2004/2006 | 33 |
| EPII | 2010 | 15 |



| Colour | Item No: | Description |
|---|---|---|
| (red) | 1 | Beam contact pads |
| (green) | 2 | Tile to tile location |
| (orange) | 3 | Dowel location boss |
| (purple) | 4 | Slotted location boss |

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*Figure 1: Sliced Beryllium Inner Wall Guard Limiter Tile Carrier Locating Features.*

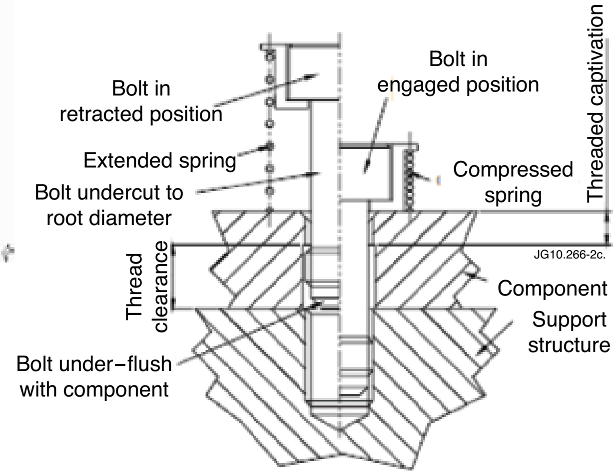



*Figure 2: Captivated pop up bolt design*

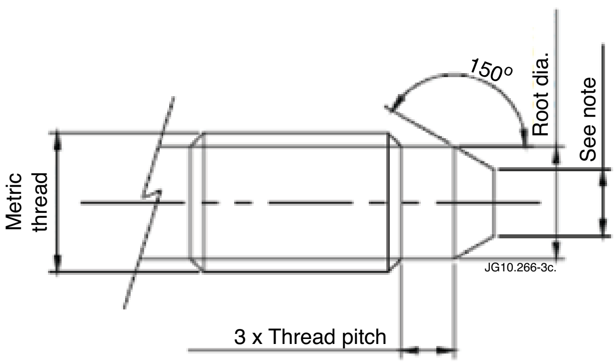



*Figure 3: Aligning bolt nose*

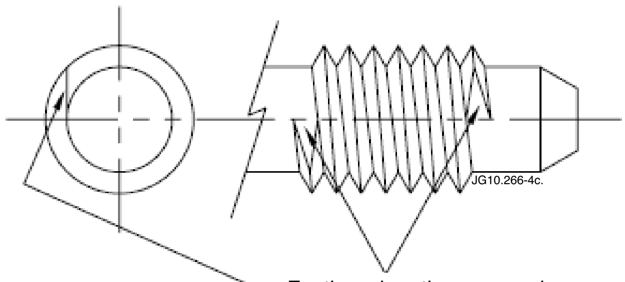
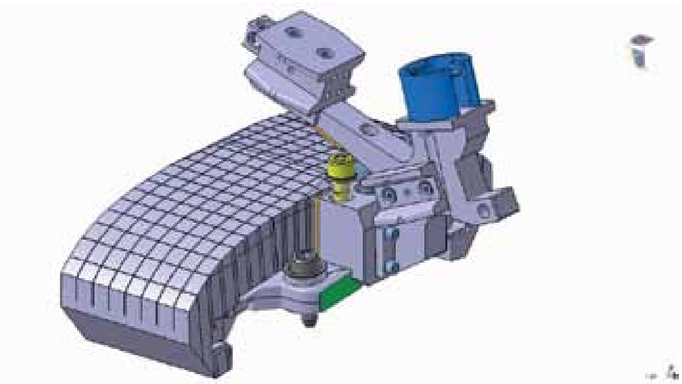



*Figure 4: Bolt feathering*



| Colour | Item No: | Description |
|---|---|---|
| | 5 | Left hand thread tool attachment bolt |
| | 6 | Tile to tile location |
| | 7 | Attachment tool park station |

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*Figure 5: Sliced Beryllium Inner Wall Guard Limiter Tile Carrier and remote handling tool.*

*Figure 6: Photograph of the manipulator and task module at work in the EPII shutdown. The manipulator is installing inconnel inner wall guard limiter tiles to the beam on the left of the photograph, and the task module is at the top of the photograph, with tiles loaded for installation.*

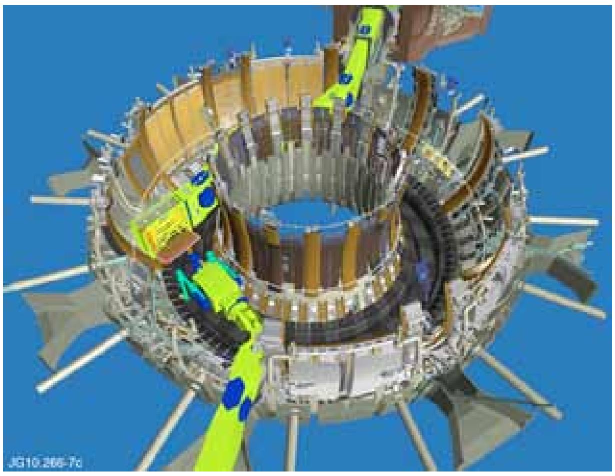


*Figure 7: The octant 1 boom deployed to the far side of the Torus interfacing with the Octant 5 boom and manipulator.*

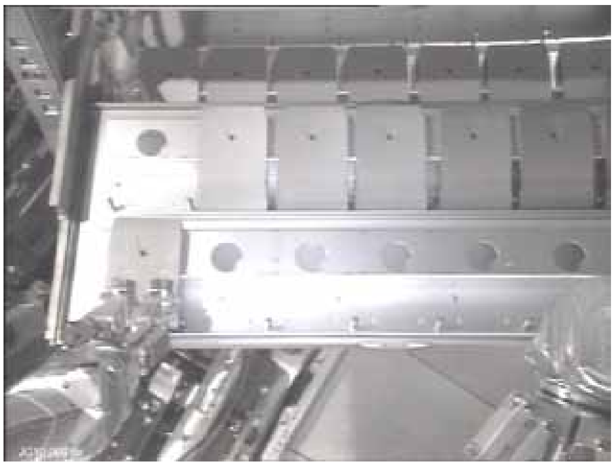

*Figure 8: Photograph of the manipulator and task module at work in the EPII shutdown, collecting inconnel inner wall guard limiter tiles from the task module drawer.*


*Figure 9: Sequence of photo's The Extended Octant 1 boom using the vertical traverse system to collect a task module during commissioning in 2009.*


*Figure 10: Example of loading guidance produced by rapid image generation software.*

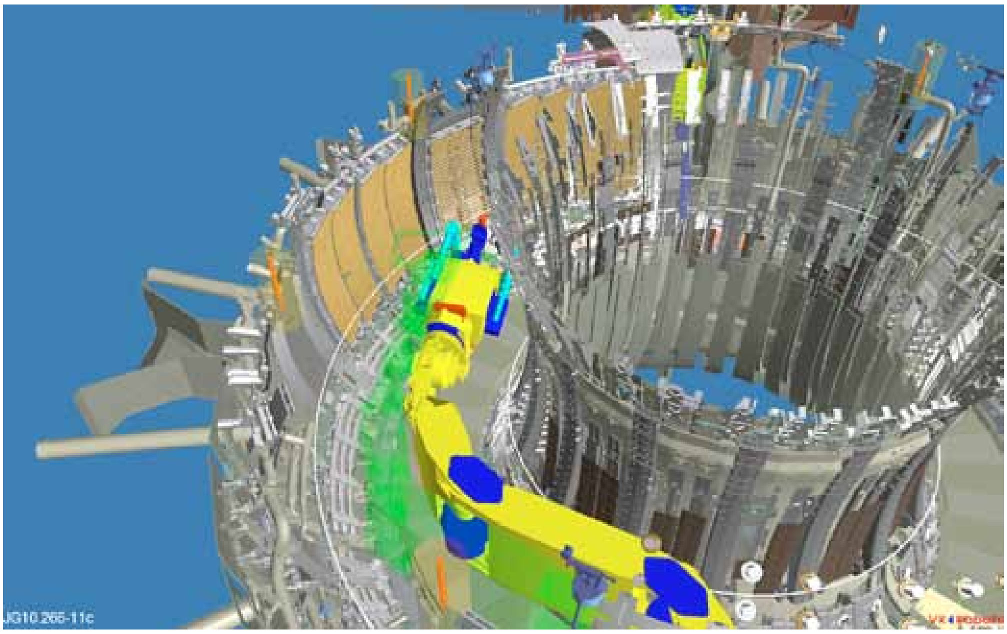


*Figure 11: Virtual reality image showing a boom movement used in the EPII shutdown.*