EFDA–JET–CP(10)07/32

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** See annex of F. Romanelli et al, "Overview of JET Results",*
(Proc. 22nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).

Preprint of Paper to be submitted for publication in Proceedings of the
26th Symposium on Fusion Technology (SOFT), Porto, Portugal
27th September 2010 - 1st October 2010

ABSTRACT

The requirement for an upgrade of the diagnostics for the JET ITER Like Wall (ILW) whilst maintaining personnel exposure to contamination as low as reasonably practicable or ALARP, has necessitated the development of a bespoke set of diagnostic components. These components, by virtue of their design and location, require a versatile yet comprehensive suite of remote handling tools to undertake their in-vessel installation. The installation of the various diagnostic components is covered in multiple tasks. Each task requires careful assessment and design of tools that can successfully interface with the components and comply with the handling and installation requirements. With remote maintenance a requirement, the looms/conduits were designed to be modular with connections which are electrically connected when the module is fitted or conversely disconnected when removed. The shape of each complex and often bulky component is verified during the design phase, to ensure that it can be delivered and installed to its specified location in the torus. This is done by matching the kinematic capabilities of the remote handling system and the path of the component through the torus by using a state of the art virtual reality system.

1. INTRODUCTION

A diverse range of diagnostic equipment is currently installed in the JET Torus to monitor both the conditions within the Torus as well as the status and performance of some of the thousands of components that all contribute to the successful generation of fusion energy. The replacement of the existing First Wall of the JET Torus with enhanced new designs for an ITER Like Wall (ILW) has resulted in many carriers being redesigned to provide a interface for new Beryllium Tiles. To monitor the performance of this new wall, an improved diagnostic system was designed for installation in parallel to the installation of the carriers and tiles.

As part of the justification for the installation of upgraded diagnostics in support of the ITER Like Wall installation, several factors relating to the manner whereby the diagnostics would be installed, either manually or remotely, needed to be evaluated in order to establish the value of the proposed options.

The factors were:

- The requirement to justify the need to expose personnel to radiation based on the principle that human exposure should be maintained as low as reasonably practicable or ALARP.
- The personnel target dose limit of 2mSv for individuals for the duration the Enhanced Phase 2 (EP2) ITER Like Wall Shutdown
- The estimated time for the manual installation of these new diagnostics and the total uptake for all personnel during this period
- The successful remote handling installation of many diagnostic systems within the JET Torus during previous shutdowns
- Consideration for lower component design costs if manually installed but at the expense of a higher total personnel radiation uptake
- Consideration for higher design costs for components that may be remotely handled as well associated tooling costs to support the remote handling tasks but minimising personal exposure.

As a result of these considerations, design for installation of diagnostic components using remote handling was implemented. The designs which followed, were undertaken with due consideration of the remote handling tooling versatility as well as its limitations.

Many criteria drove the designs for the remote handling compatibility of the diagnostic systems and the associated remote handling tooling and systems that would need to be designed to accomplish the various tasks specified for the Second Enhanced Phase (EP2) Shutdown that define the provision and installation of the ILW diagnostics for this phase.

These components, by virtue of their design and location, drove the need for a versatile yet comprehensive suite of remote handling tools to undertake their in-vessel installation.

The installation of the various diagnostic components is covered in multiple tasks. These tasks range from:

- fitment of components with embedded diagnostics
- welding rails to the Vessel Wall as anchor points
- fitment of trunking to these anchor points
- installation of diagnostic looms within the trunking
- fitment of protective lids to the trunking and finally
- connecting the looms to the embedded diagnostics and the torus diagnostic wiring

2. THE TASKS

2.1. THE HANDLING OF THE ILW EMBEDDED DIAGNOSTICS

The range of diagnostics components that are handled can vary from a small Loom Test Plug at few hundred grams, midsize tiles and carriers with thermocouples, inductive coils and similar sensors, to conduits and looms over two meters in length, all of which are comfortably handled by the Mascot manipulator. Larger diagnostics, like an entire Antenna, are handled directly by the JET Remote Handling Octant 5 Boom via an attached bespoke End Effector with an integral Force Moment Sensor.

2.2. WELDING OF DIAGNOSTIC SUPPORT RAILS TO THE WALL

Diagnostic loom trunking and conduits are a necessity that occupies space that is vitally needed for other purposes and therefore needs to be as compact and efficiently routed as designs permit. The trunking also needed to be securely mounted to ensure that the magnetic forces do not affect its installation integrity. To achieve these goals, multi-threaded male Vee Rails are precisely located and remotely welded to the vessel wall using an autogenous weld process in readiness for female Vee Blocks to be mounted to the Vee Rails.

The precision of the Vee Rail location, integrity of the weld earth circuit, weld power line, weld control and other factors all need to be effectively controlled to ensure the weld meets the stringent requirements of the specifications.

2.2.1 Development of Remote Handling Welding Tools

The successful and repeatedly welding of each Vee Rail into unique positions on the Vessel

Wall demanded tooling that was adaptable and versatile. In addition to this, each weld tool had to incorporate the accurate and rigid retainment of each Vee Rail and control the position of the Tungsten Inert Gas (TIG) Weld Heads over the Vee Rail during the welding process.

Finally, the repeatability of the tool and weld settings had to be consistent. To establish this consistency, "preproduction sample welds" (PPS) were undertaken before each in-vessel weld using the actual tool to be used for the task. This process ensured an extremely high level of reliability over the range of locations and orientations.

2.2.2 Development of Remote Handling Welding Unit

With the location of the Weld Rails around the periphery of the vessel and the Welding Machines remaining outside the vessel and on top of the Octant 1 support facility, the weld cable circuit measured approximately seventy metres in length. Initial trials highlighted the unreliability of arc initiation with cable runs of this length using modern welding units and further development work was needed to establish the need for specific enhancements that would not affect the operation of the Boom yet still ensure successful repeated initial arc strikes at the TIG Weld Head when used in-vessel. Success was achieved after many trials via the development of bespoke in-line high frequency arc-start units located local to the welding task in a Welding Task Module that was also capable of transporting the welding cables and a detachable earth return cable.

2.2.3 Remote Handling Welding Cable Path

With the many locations of the Vee Rails and a setup necessary before use, the need to provide an efficient delivery of welding power to the weld site was imperative. The number of serial cable connections were kept to a minimum and where connections were necessary, the use of approved high efficiency connectors was specified. Simple but effective clamped connections were chosen for external semi-permanent use while Dinze Connectors with known high efficiency, high reliability connection and disconnection action were specified for handling with the MASCOT manipulator.

This connection point and the purpose designed Arc-Start Unit were housed in a bespoke, configurable Welding Task Module transported at the end of the Octant 1 Boom. This location was to allow the unit to be positioned within easy reach of the MASCOT Manipulator and hence increasing productivity.

Using this setup, the locations of the 22 Vee Rails could be sequentially accessed and the setup time for Earth clamp and cable deployment and retrieval time minimised. The precise location of the Welding Tool and prefitted Vee Rail was achieved by various means with Template Jigs fitted to the Weld Tool for abutting known surveyed in-vessel features being the most common method.

On completion of this task, to verify the position of all these Vee Rails, photogrammetry targets were fitted to each Vee Rail interface so that a survey could capture and transfer all their in-vessel positional data for integration with the Trunking and Conduit designs.

2.3 FITMENT OF DIAGNOSTIC CONDUIT AND TRUNKING

The installation of the trunking and looms require the MASCOT to handle components varying in size and mass from small and light to others approximately two metres in length and 14kg mass.

As the loom runs are extensive, the need for a modular system of trunking and or conduiting to both contain and protect the looms was obvious. However, the design of the diagnostic conduit and trunking highlighted conflicting scenarios. Whether the use of long or short conduit and trunking was selected as the preferred diagnostic enclosure, contradictory advantages and disadvantages become apparent.

The greater the length of the conduit or trunking the more difficult it becomes to manufacture each one to overall geometrical tolerances and the more difficult it is to remotely handle and install due to its excessive size. The shorter the conduit or trunking is, the greater the time required to design and produce joints to tolerance in sheet metal, that will be acceptable for remotely assembly invessel–though generally the remote handling is simplified due to the reduction in component size.

Each condition therefore requires specific design analysis and optimisation to ensure the most effective solution is chosen to match the handling and kinematic capability of the remote handling system.

Unpopulated trunking, produced using heavier gauge sheet metal is generally rigid but requires successive tasks to populate with a loom and finally to fit a protective cover or lid. Effective alignment features must be incorporated on both the trunking and lid to ease fastener mating and minimise remote assembly times. Prewired conduit is heavier due to the integral wiring and generally manufactured with a thinner shell. Longer conduits usually need to be supported by pre-attached strongback tools to minimise flexing during transportation as well as to aid positioning during installation.

The larger items in this range are also transported into the torus by the Octant 1 Boom fitted with a Tray Support Tine. To simplify collection by MASCOT, the conduit may be mounted on a bespoke Turntable Tray mounted on the Octant 1 Boom long tine. The MASCOT may therefore rotationally position the tray before grasping the remote handling tool attached to the component.
The component is then released from the tray and lifted to the installation position on the vessel walls or even overhead to the roof of the torus for installation. This manipulation of the components and mating tool is repeated many times, in many orientations and often in difficult to reach installation positions. Virtual Reality (VR) models and animated flight paths assist in ensuring a clear navigable path is assured before the task is undertaken.

Once the trunking or conduits with their associated looms, have been installed, the MASCOT manipulator is used to connect the diagnostic loom plugs into the torus sockets that have a mating process designed for high compliance yet ensuring accurate alignment.

2.2.3 Larger ILW Diagnostics

Some of the JET Diagnostic systems will be removed from the Torus to allow improvement work to be undertaken on them. A typical example of this is the Toroidal Alfvén Eigenmodes (TAE) [2] Antenna which is used to excite modes in a specific range of frequencies. [2]

The Remote handling of this antenna is undertaken using an End Effector mounted on the end of the Octant 5 Boom and a Six-Axis Force Moment Sensor. The design of the antenna to Torus wall mounting and the effective use of the Six-Axis Force Moment Sensor allows for the installation and removal of the Antenna in a precise and controlled manner with minimal residual contact forces or moments when the Antenna to End Effector coupling is disengaged. This preciseness helps to ensure no additional induced stresses are placed on the mounting bolts or alignment dowels other than those considered to exist during operations and accommodated during the analysis and design of the antenna. As with other diagnostics the remote handling compatible plugs are used to connect the antenna to the torus diagnostic wiring.

CONCLUSIONS

The many requirements for the remote installation of the ILW Diagnostics have been achieved using designs that although initiated with innovative thinking have evolved considering functionality and engineering principles foremost to ensure reliability. In most cases mock-ups of components and tooling were produced and trialled to assist in confirming that design criteria, remote handling functionality and repeatability in use had been met or whether further development was warranted.

REFERENCES

[1]. Developments in remote metrology at JET T. Mindham, G. Sandford, G. Hermon, C. Belcher, N. Pace and JET EFDA contributors 26th Symposium on Fusion Technology (SOFT), Porto, Portugal (27th September – 1st October 2010)

[2]. A Real-Time Synchronous Detector for the TAE Antenna Diagnostic at JET D. Alves, R. Coelho, A. Klein, T. Panis, A. Murari and JET EFDA contributors* 16th IEEE NPSS Real Time Conference, Beijing, China. (10th May 2009 - 15th May 2009).

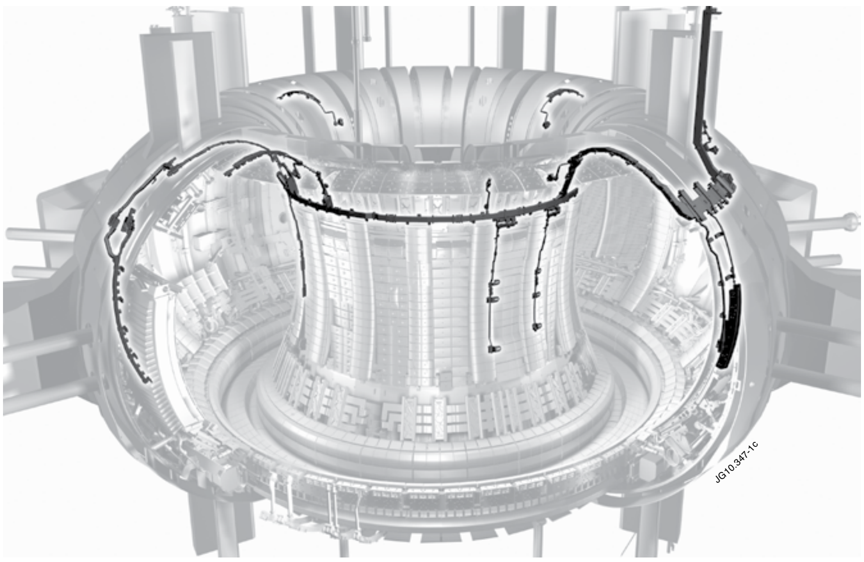

Figure 1: Layout of the Embedded Diagnostic Trunking and Conduits (coloured dark) to be installed in the JET Tokamak.

Figure 2: View of a Dump Plate Thermocouple and Halo Coil Conduit /Loom and RH Tool designed for the JET Torus.

Figure 3: Diagnostic JET Torus Welded Rail.

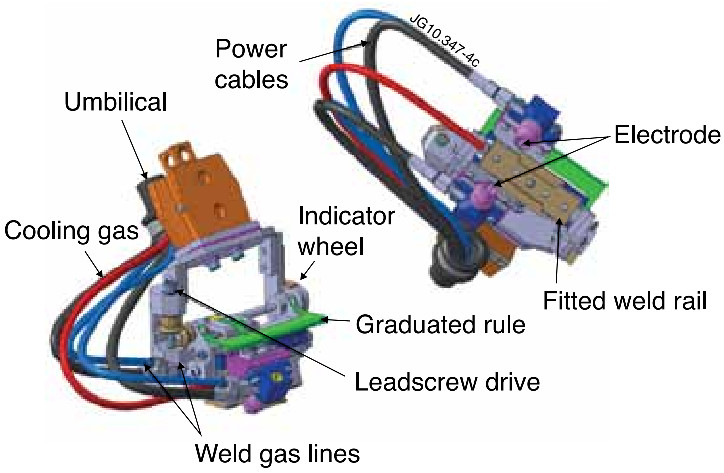

Figure 4: Pictorial views of the Remote Handling Welding Tool with a Weld Rail fitted ready for welding.

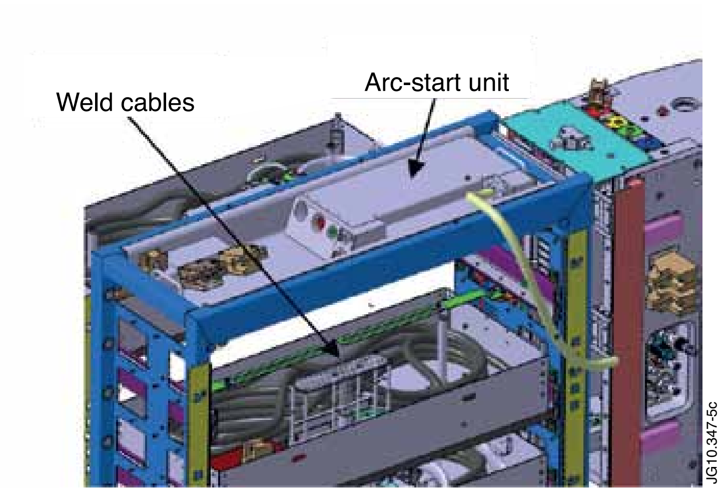

Figure 5: The Remote Handling Octant 1 Boom with a Task Module prepared for in-Vessel Welding.

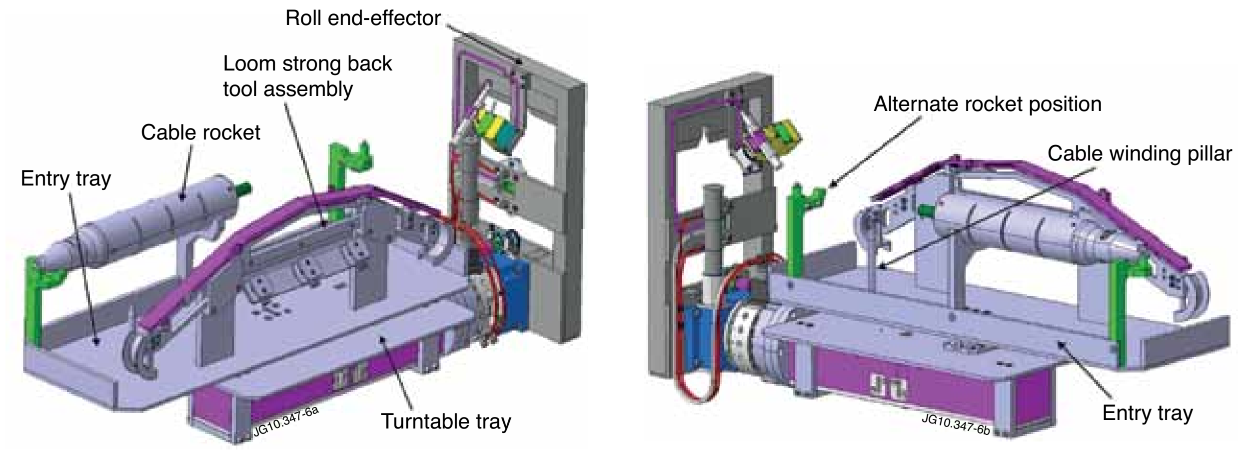

Figure 6: Diagnostic Conduits and Remote Handling Tools on a Turntable Tray.

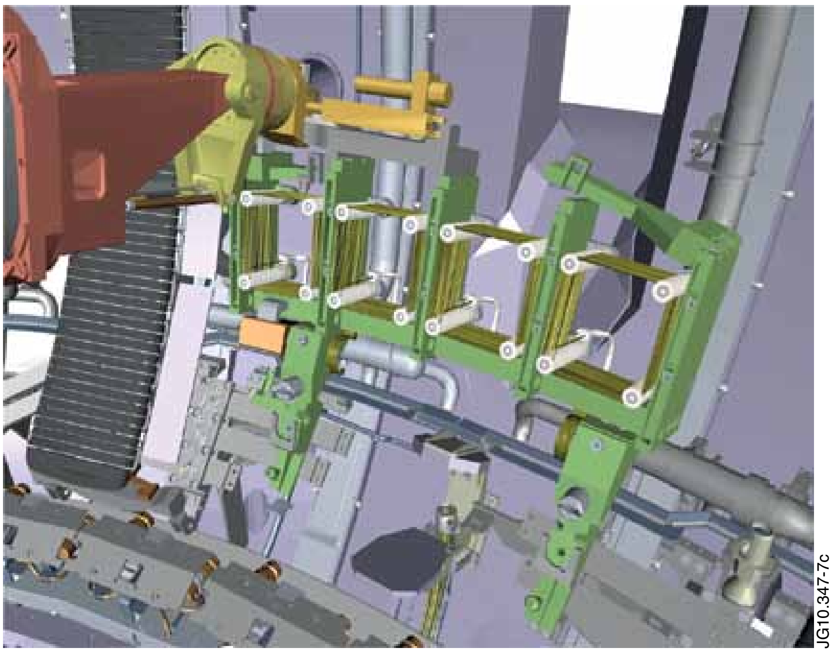

Figure 7: Remote Handling of one of the two TAE Antenna installed in the JET Torus.