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Concept design of high precision portable machines for the in-situ manufacturing of the ITER vacuum vessel

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Abstract

The vacuum vessel of ITER is a paradigmatic example of a gargantuan system that can only be processed in-situ and from the inside. Its geometry is very complex and it is highly unlikely that all the welding, machining and inspection operations can be performed in such a harsh environment with existing commercially available system. Moreover, the vacuum vessel of ITER presents a wide variety of different positions where manufacturing systems need to be located and work. This paper shows a thorough study of the requirements of said application and the definition and concept design of an array of portable drilling and milling machines to perform all the necessary manufacturing, assembly and inspection cases within the vessel. In the inter-sector areas the available space and the requested machine tool centre point position and orientation are studied and a solution machine is proposed. For the ports, three different machine systems are proposed. The research shows that four different portable milling machines are capable of performing the requested operations, based on a mix of serial kinematic and hybrid (combination of serial and parallel kinematic) machines.

Keywords: portable machines, in-situ, maintenance, manufacturing, inspection, serial kinematics, hybrid kinematics, vacuum vessel

1. Main section heading

The vacuum vessel (VV) of ITER is a large system that can only be processed in-situ and from the inside[1]. Its assembly implies performing at least the following operations: (i) measurement of the existing space between two consecutive sectors. (ii) positioning of the splice plates between the sectors (approximate weight 150Kg), (iii) welding the splice plates to the sector shells, (iv) repair operations, including machining of welding seams, (vi) leak tests of the welding seams, (vi) any other contingency operation not planned. These operations should be possible in any configuration, upside-down and rotating 360º following the internal surface of the vacuum vessel.

As for the welding and cutting operations the development of the remote system was completed in 1998 with support from the Home Team in USA [2]; a serial kinematic robot arm on a rail-mounted vehicle moving on the guide rail. However, such system is not capable of carrying out machining inside the vacuum vessel. To address these operations, H. Wu presented an Intersector Welding Robot (IWR) [3] based on a parallel kinematic architecture The higher stiffness/weight ratio of parallel kinematics made the IWR take the lead and it was considered as the optimum solution. However, it is not capable of reaching every single welding seam and port detail given its lack of overall dexterity.

This paper reports on a thorough study of the requirements of the post-welding operations of the assembly process of the VV of ITER. Then, a streamlined array of machines is proposed and their specifications defined to reach every single point needing manufacturing and inspection. Their overall utility and completeness is finally studied to prove that proposed solutions are complete and valid.

2. Process requirements

The geometry of the Vacuum vessel (VV) of ITER is very complex and a deep study shows that all the welding, machining and inspection operations can not be performed with only one bespoke system. There are two different locations where operations must be performed (Fig.1).

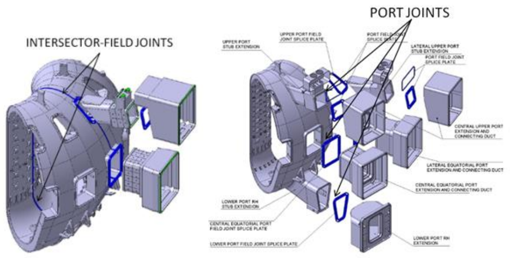

Figure 1. Intersector joints and port joints within the VV

Intersector joints: Access to intersector interfaces is of moderate difficulty and joints and features for machining are regular and long. These areas can be reached with a machining unit from inside the VV. This field joints could be performed (machined, and inspected) with a robust system with short distance between structure fixing points and the tool centre point (TCP) and the ability to work in a continuous mode. Therefore, in this case flexibility and positioning capability requirements are low and the stiffness required depends on the machining process itself.

The stringent space requirements to access the outer wall from the inside can be seen in Fig.2:

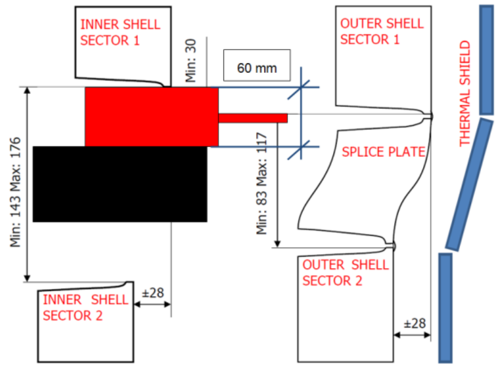

Figure 2. Space restrictions in between walls

Port joints: Access to port joints is remarkably difficult and joints and features for machining are short and demand a challenging configuration to the machining unit. High arm distances between fixing points and the tool centre point appear if these areas are to be reached with a machining unit from inside the VV. Therefore, in this case flexibility and positioning capability requirements and stiffness minimum values are high in a notably distant TCP.

In both cases, vacuum is released to perform the post-welding operations, which are performed in ambient. Besides this, the requirements for the system to perform the machining tasks are:

Accuracy +/- 0.1 mm;
Dynamic machining forces 3 kN;
Handling payload 6 kN,
Mass < 1 ton;
Speed up to 1.2 m/min

2. Machine specifications

Two sets of machines are proposed for these two different places where post-assembly operations are needed.

2.1. Multiaxis machine for intersector operations

For intersector joints, the system proposed essentially consists of a platform moving on rails that carries the rest of the elements. This base includes: a coarse X along the rails, a fine X axis (feed drive) and a fine Y drive. Strokes are X →195mm, Y→ 400mm and Z → 400mm. On top of it, a parallel kinematic platform is included to deliver the necessary adjustments and rotation degrees of freedom. Minor traslations and tiny rotations will be performed by means of this intermediate and stand-alone platform. Once a position and orientation is achieved, the parallel platform shall not move during machining operations which must be solely perfomed by the X-Y axes of the machine. And finally, the machine includes a payload structure equipped with the spindle, tools and camera systems. This structure shall have a fine Z Axis slide to cover the distance between the inner and the outer wall and the appropriate depth of cut. This structure carries a variety of elements: two different and parallel machining spindles (for grinding and milling/drilling) operations; a spindle changer system to deploy one of these two spindle systems and place them in “work mode”; chip aspiration devices, protections and dry cooling elements and camera systems to perform the inter-referrencing between machine and VV.

Fig.3 shows the details of the manufacturing system whereas Fig.4 shows its ability to achieve the requested positions and orientations in the worst-case-scenario of the VV.

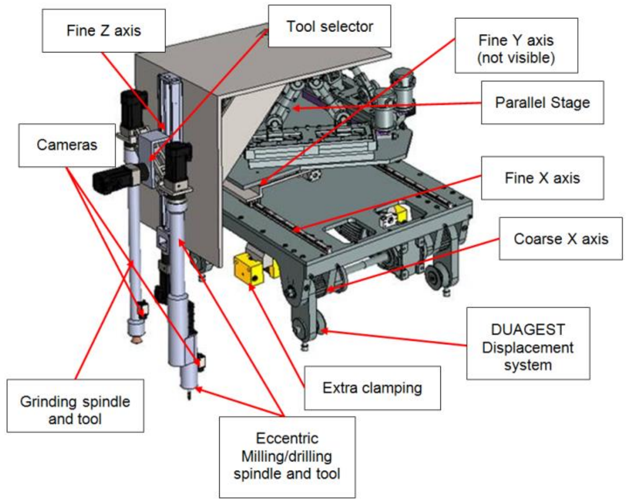

Figure 3. Concept design of the machine for intersector operations

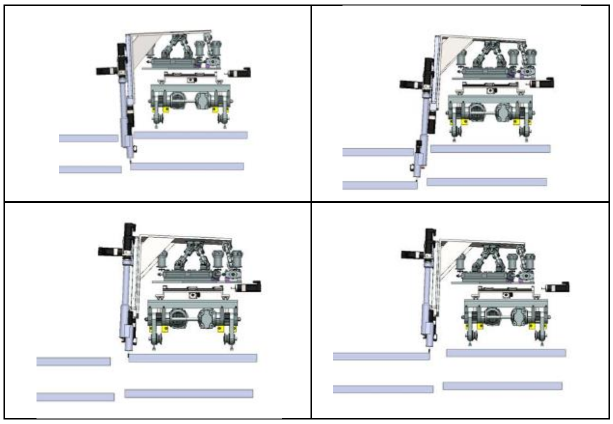

Figure 4. Machine TCP pose capabilities in worst positions

2.1. Array of miniature machines for ports

The operations in the ports will be covered by an array of miniature machines especially devoted to applications in each and every port structure. The following figure shows three elements that are enough for the application.

Figure 5. Array of possible machines for ports

2. Conclusions

The requirements of the post welding operations of the VV have been presented and four different portable milling machines are proposed which cover the requested operations.

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