ROBOTIZED SYSTEM FOR THE ISNPECTION OF ITER FIRST WALL PANELS BY UT

CARLOS SILVESTRE MARRODÁN
Project Manager
TECNATOM

M.ª CARMEN PÉREZ MELGUIZO
Mechanical System responsible
TECNATOM

JOSÉ AMADOR SILLERO MARÍN
Manager Technology
TECNATOM

The **ITER** (International Thermonuclear Experimental Reactor) nuclear fusion experimental reactor is the largest Tokamak machine ever built, multiplying by 10 the volume of plasma previously achieved, becoming the fifth most expensive project in history, and is the fundamental demonstration of the viability of nuclear fusion as a source of unlimited energy, Safe and free of emissions and waste. Among the characteristics of the reactor, we highlight:

- Weight of 23 000 tons.
- It will reach temperatures of 150 million degrees.
- It will produce 500 MW of energy
- Consisting of 5 components (Figure 1):
  - (1) magnets (magnetic field generating system including toroidal and poloidal field coils)
  - (2) Vacuum Vessel (hermetic container shaped like a double-walled torus with 44 accesses through the ports)
  - (3) blanket (shield consisting of the First Wall Panels that protects the inner wall of the vessel)
  - (4) divertor (reaction residue extractor)
  - (5) Cryostat (cryostat that cools and ensures vacuum conditions)

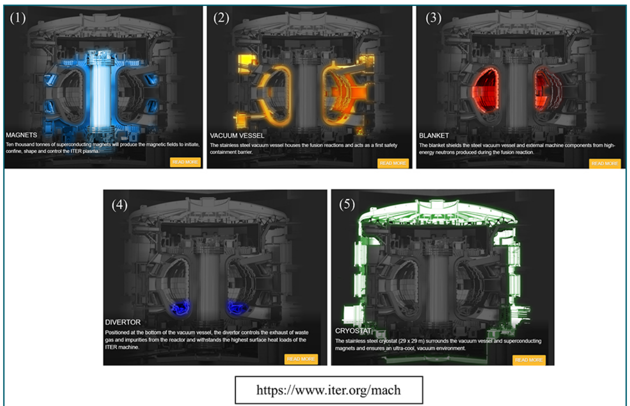

Figure 1. Position of the different components of the Tokamak nuclear fusion reactor.

As it is a nuclear facility involving different international regulatory bodies – together with the complexity of the design and manufacturing requirements – the **greatest technical and organizational effort** has been necessary to successfully complete the mandated activities. Within this framework, Tecnatom plays a fundamental role in the inspection through Non-Destructive Testing of several critical components during their manufacture.

The First Wall Panels (FWP) are the components that cover the inside of the vessel and are in direct contact with the plasma. They are manufactured by joining various materi-

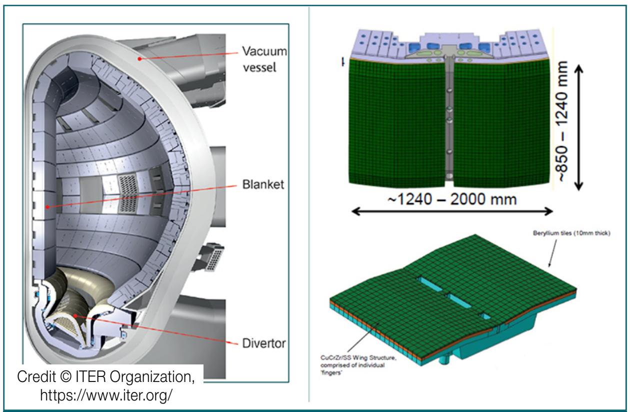

Figure 2. Position of the FWPs inside the vacuum vessel, overall dimensions and main structure.

als such as beryllium, stainless steel and a copper-chromium-zirconium alloy, joined in three stages by the process called HIP (*Hot Isostatic Pressing*) (Figure 2).

Within the general FWP manufacturing project, Tecnatom's scope of responsibility is the development of ultrasonic inspection techniques (UT), the design and supply of the inspection system (on which this work will focus) and the inspection of the first FWPs to be manufactured.The architecture of the selected inspection system consists of a robotic cell, with TAURUS 2.0 technology developed by Tecnatom, using different immersion tanks for UT inspection of the FWP in their successive manufacturing stages (HIP1-HIP2-HIP3). The cell has been designed to cover the entire production phase, and is applicable to all FWP models that could be developed by the main contractor FBL (Fusion Business Leadership, consortium formed by Empresarios Agrupados and *Leading Metalmechanic Solutions*).

PROJECT DEVELOPMENT

Among the main challenges of this project is the variability of the geometries of both the different areas of each panel and the various models to be inspected, together with the fact that their shape and size also change in each of the three phases of the manufacturing process.

All this required a detailed geometric study to define the inspection technique and the trajectories to be executed by the robot, having designed an inspection strategy based on the use of different ultrasonic probes that have been validated against a series of demonstration blocks and representative models. In addition, the high weight of the panels and the needs for precision in their positioning have made necessary the innovative design of tooling in the inspection tanks that provide great versatility and repeatability for handling.

The main challenges of the project from the ultrasonic point of view are:

- The different materials that make up the panel.
- Thedifferent thicknesses of each material.
- Complex geometries.
- The critical size of the defect to detect represented by small diameter flat-bottomed holes (FBH).

The inspection procedure and the robotic system will be validated by inspecting a three-panel pre-series, after which the manufacture of the first series of 27 panels of two different models will begin, which will also be carried out by Tecnatom.

During 2021, the development of inspection techniques and procedures began, along with the design, manufacture, and assembly of the robotic system, which has been integrated and tuned in the customer's facilities and validated in 2022.

Prior to this contract with FBL, Tecnatom had already investigated the inspection of FWPs in the CDTI Fusion Technologies project, in cooperation with Leading Metalmechanics

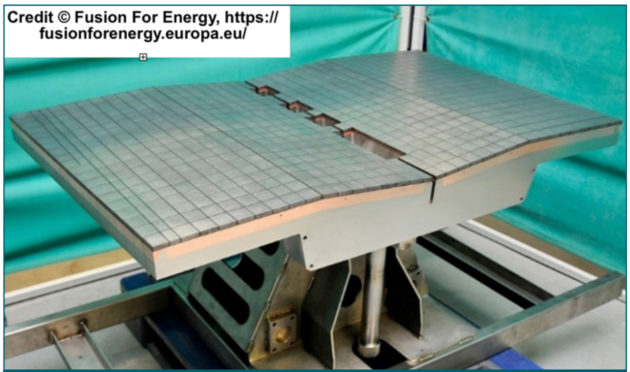

Figure 3. View of the full-scale FWP prototype manufactured in previous stages of the project.

Solutions, S.L. and HEDISA, S.A.U. (Figure 3).

System design

Taking into account, on the one hand, the inputs of the design of the inspection techniques carried out in the laboratory using the blocks, as well as on the other, the geometry of the final panels of the FWP, the mechanical designs of the inspection cell were carried out (robot, layout or arrangement of the elements in space, immersion tanks, inspection modules, stand of modules to perform the automatic change of the same ...), electrical and wiring designs, design of the water system and design of the control system, with the TAURUS 2.0 technology, owned by Tecnatom (Figure 4).

For the design of the inspection trajectories, which allowed to check the ranges of the robot and design the positioning of the panels in the immersion tanks, as well as the necessary tooling of the parts and the ultrasonic inspection modules, the GENTRAY 3 complex trajectory generation software, developed by Tecnatom, was used and the industrial application ROBOmove, which allows to simulate possible collisions and process the trajectories in a language understandable by the robot.

In GENTRAY 3, the geometries of the parts and the 3D models of the inspection modules are entered in CAD format (STEP) and, entering the necessary parameters according to the type of inspection, the lines of the trajectory that the robot will then follow during the inspection are automatically generated (Figura 5).

After several iterations in the designs of the modules, it was possible to close some models that were ideal for inspections, guaranteeing the reach to all the necessary positions

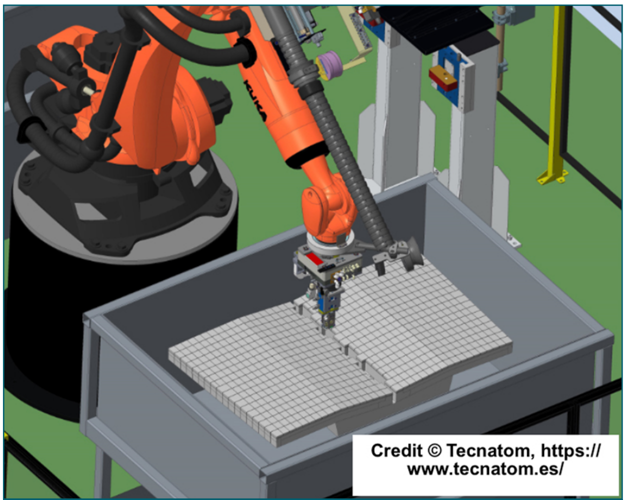

Figure 4. Detail of robot positioning during panel inspection in one of the HIP phases.

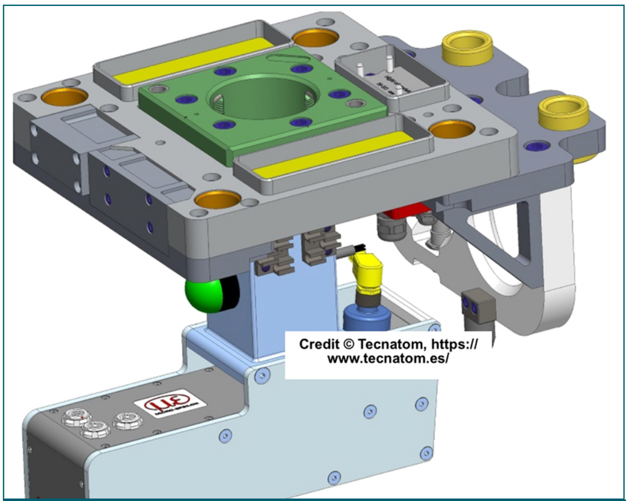

Figure 6. 2D laser module.

and minimizing their dimensions and weights to optimize the dynamics of the robot. The final modules to be used in the system would then be:

- 2D Laser Module (Figura 6): to acquire point clouds: to generate the geometry of the part, if necessary, or to position the parts in the inspection cell.
- Inspection modules for the different joints to be inspected in each process.

Table I shows other relevant characteristics of the robotic system, selected from the development of UT techniques and laboratory tests, and through the simulation of inspection trajectories to check coating, robot scope, etc.

System supplies, assembly, integration and tuning

After carrying out the electromechanical assembly of the equipment components and the tuning of the robot control system, the functional tuning of the ultrasound was carried out. The initial inspection trajectories were adjusted and, together with the optimal parameters identified in the development of the UT techniques, it was possible to carry out the inspection of the calibration and validation blocks, as a preliminary phase to the inspection of the future panels.

Validation

During the past April 17th and July 20th were carried out the internal validation of the system (equivalent to the usual FAT: Factory Acceptance Tests), and from October 26th to 28th the validation at the customer's facilities (SAT: Site Acceptance Tests). Both in the presence of the client FBL and F4E (European Union body that manages the EU contribution to the ITER project). These tests were carried out on a set of calibration blocks and representative models of the joints with very satisfactory results, leaving thesystem ready to be sent to the FBL facilities.

Additionally, throughout the project, an expansion of scope has been required to include the inspection of new joints

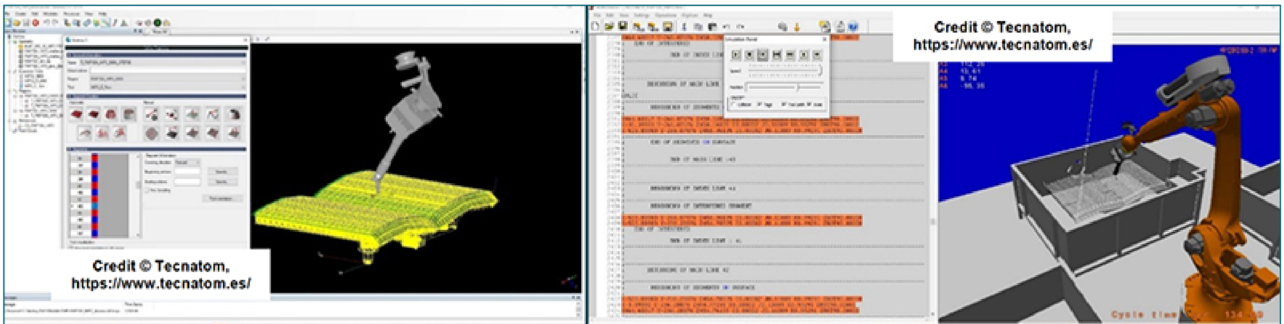

Figure 5. Trajectory design with GENTRAY 3 (left) and ROBOmove (right).

System component or feature	Description
Ultrasonic electronics	FPR-8A, developed by Tecnatom
Ultrasonic Acquisition Software	InspectView, developed by Tecnatom
Robot model	WHO, KR120 R3100-2F
Means of coupling	Water, by total immersion with the vats
Ultrasound technique	Pulse-Echo, with straight beam
Signal type	Full wave
Theoretical speed of sound	5.750 m/s (SS), 1.480 m/s (water) 4.660 m/s (CuCrZr) and 13.070 m/s (Be).

Table I. Other important features of the robotic system.

not initially planned. All these activities are carried out under contract No. F4E-OMF-900-03 that FBL maintains with F4E, and which is one of several of the contracts in which Tecnatom participates for ITER, demonstrating our good reputation in the nuclear sector worldwide.

Next actions in the project

Once the system has been assembled at the customer's facilities in San Felices de Buelna (Cantabria) and the system has been tuned, it will be finally validated by inspecting the 3 FWPs that make up the pre-series during the first half of 2023.

JUSTIFICATION OF THE SELECTED INSPECTION SYSTEM MODEL

The high level of development and versatility of RABIT 2.0 technology allows the design and customization of TAURUS 2.0 inspection cells adapted to customer needs (mostly aeronautical until now, counting Tecnatom with references of more than 40 robotic systems delivered, since 2012). In this way, using the different basic developments (UT electronics, trajectory generation, robot control, UT modules, laser scanner, etc.), systems based on one or two robots are designed, with additional elements such as linear tracks, immersion tanks, yokes for transmission inspection, etc.

This type of system provides high productivity in manufacturing processes, given the high inspection speeds and the repeatability of the process, since the robot itself and the tooling has been designed to achieve this great repeatability in the positioning of the panels in the tanks and, consequently, of the inspection trajectories. In addition, it ensures uniformity in the coupling and in the ultrasonic signal, obtaining high inspection speeds without contact. The inspection cell (robot scope and size of immersion tanks) has been sized to be able to inspect the three initial FWP models awarded to FBL and future ones.

CONCLUSIONS

This article presents the work carried out for the design, manufacture and tuning of the robotic system for the ultrasonic inspection of the FWP (*First Wall Panels*) of ITER, as well as the generation of procedures to carry out these inspections, based first on blocks and then on real models.The results of these inspections obtained with the robotic system have allowed to corroborate, once again, that the robots provide precision and repeatability in the results, being an optimal automatic inspection architecture, where costs are low, maintenance very simple, and productivity ratios very high. With this and other projects for ITER, whose beginnings date back to 2010, Tecnatom has earned recognition for the experience of its experts in ultrasonic techniques (conventional and *phased array*) and for their continuous effort, for many years, to satisfy the highly demanding technical requirements such as those of the ITER reactor. After the qualification of the UT techniques, Tecnatom has obtained inspection contracts during the manufacturing phase of these components, and customer support contracts with ITER *Organization* (final customer).

THANKS

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