Topics: **TEC-ITR**

ADVANCES IN EUROPEAN IN-KIND CONTRIBUTIONS TO PLASMA DIAGNOSTICS AND PORT INTEGRATION FOR ITER

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ITER, a next-generation magnetic confinement fusion device, is currently under construction in France by a consortium of 35 nations, led by ITER Organisation (IO). Fusion for Energy (F4E) is the European Domestic Agency (DA) for ITER and provides components and systems to ITER "in kind", on behalf of EURATOM.

Diagnostics have an important role on ITER by providing information to protect ITER from damage, to allow the plasma to be controlled, and to study and optimize the plasma. There are around 50 Diagnostics on ITER (counting the suite of 24 different, magnetics sensors as one Diagnostic) [1]. F4E is responsible for eight Diagnostics and six ports, housing 16 Diagnostics provided by four DAs and IO, as well as the electrical systems providing connection to in-vessel Diagnostics. Six of the diagnostics and one port are required for start of research operations on ITER.

The Diagnostics provided by F4E employ a wide range of diagnostic techniques, using sensors spanning the electromagnetic spectrum, from X-rays to radio waves, as well as making particle-based measurements. The design of diagnostic components and systems for ITER faces several challenges: high levels of radiation, significant thermal and magnetic loads, ultra-high vacuum requirements, limited space, limited access during and after operations, tritium confinement and regulatory control [2]. These challenges limit the material options, require specific manufacturing and testing processes, and must be supported by strict qualification processes and extensive QA documentation.

The Core Plasma Thomson Scattering System (CPTS) is a port-based optical system that measures the electron temperature and density in the core plasma by spectral analysis of light scattered by electrons in the plasma from a powerful, near-IR laser. The system extends from the diagnostics building to the vacuum vessel, including lasers and alignment system, collection optics (mirrors), shutters and a mirror cleaning system, optical fibre bundles, laser beam dump (mounted in the ITER first wall), polychromators and I&C. The system is in final design, with design completion and start of manufacturing expected in 2027.

The Collective Thomson Scattering (CTS) system will measure the density and velocity distribution function of fast ions and confined alpha particles; the latter having much higher relative densities than in present fusion machines creating a substantial effect on the overall dynamics of the ITER fusion plasma. The CTS introduces a 1MW, 60 GHz mm-wave beam into the plasma, via waveguides, mirrors and antennas. Other mirrors collect mm-wave radiation scattered by the plasma across its cross section. The F4E responsibility covers the front-end of the CTS, integrated into an equatorial port plug, for which the design phase is complete, and manufacturing has begun.

The equatorial visible/infra-red (IR) Wide-Angle Viewing System (WAVS) provides a visible light view of the plasma and measures the temperature of plasma facing components in the ITER vessel. Both the visible and IR views provide information to control the plasma and, in the case of the IR, also to avoid component damage from excess heating. WAVS uses an array of visible and IR cameras, distributed over 15 lines of sight in 4 equatorial ports, to ensure that most of the plasma facing components are viewed. Mirrors in the port plug, protected by shutters and a mirror cleaning system, are used to collect the light. Lenses maintain the quality of the image over ~15m onto the camera sensors in the port cell, where radiation levels are lower. The design for one equatorial port is complete, and manufacturing of the port plug components will begin in 2025.

The core plasma Charge Exchange Recombination Spectrometer (CXRS) is an optical, port-based system providing spatially resolved measurements of the fuel ion temperature, plasma rotation, and impurity concentrations, by analysing light emitted during charge exchange between plasma ions and energetic neutrals, injected by a dedicated neutral beam system (not supplied by F4E). The system includes collection optics (mirrors), shutters and a mirror cleaning system, optical fibre bundles, high resolution spectrometers and I&C. Port plug components of the system are in final design, with design completion and start of manufacturing expected in 2027.

The Diagnostic Pressure Gauges (DPGs) are Bayard-Alpert ionization gauges, adapted for operation in a high magnetic field. They measure the neutral gas pressure at several positions in the ITER divertor, lower ports and the main chamber wall. The DPG uses an indirectly heated zirconium carbide crystal as a source of electrons to ionise the neutral gas. The number of ions produced is directly related to the pressure of the gas and is measured by the current of ions flowing to a collection electrode. Maintaining the electron source over the ITER lifetime poses significant design challenges e.g. to resist creep and fatigue in support structures, especially since currents of several Amps are required to heat the crystal resulting in large forces due to the high magnetic field in ITER. The system is close to completing the final design and start of manufacturing is expected in 2026.

The Magnetics Diagnostics consists of 24 different sensors, of which F4E are responsible for 11. All of these are coils, designed to measure the rate of change of the different components of the magnetic field, at discrete locations inside and outside the vacuum vessel, divertor and in the TF coils. In many cases, the value of the field is obtained by electronically integrating the signal. Due to the long pulses on ITER and the demanding requirements for sensitivity and signal-to-noise, integrators have been developed by F4E that are 100 times more precise than previous state-of-the-art systems. Around 900 pick-up and Rogowski coils have been already delivered to ITER.

The Radial Neutron Camera (RNC) is a port-based system comprising by two collimating structures (one in-vacuum and the other in-air) viewing the plasma radially through vertical slots in the diagnostic shielding module (DSM) of the port plug. The RNC measures the uncollided 14 MeV and 2.5 MeV neutrons from deuterium-tritium (DT) and deuterium-deuterium (DD) fusion reactions through an array of neutron flux detectors located at the rear of the collimators. Challenges include development of neutron flux detectors able to survive in the high neutron radiation environment. The in-air system is in the final design and the in-vacuum system is already under manufacture.

Tokamak Services provide the electrical and mechanical infrastructure to extract the signals produced by diagnostic sensors. Its scope embraces electrical feedthroughs, remote-handling connectors, mechanical supports or mineral-insulated cables. A significant fraction of the project has been already delivered to ITER site, while the most challenging items are either finishing its design or starting its manufacturing.

For the six ports under F4E responsibility, the design of the diagnostic ports encompasses both in-vessel and ex-vessel structures as well as design integration of the Diagnostic systems housed in the ports. The in-vessel structures, situated within the port plugs, include the Diagnostic Shielding Modules, which are regarded as the most critical elements due to the challenging environment and the complexity of the Diagnostic sub-assemblies that they host. Additionally, these components feature cooling water, gas, and electrical services, including feedthroughs installed at the primary confinement barrier, which provide first confinement barrier for tritium and other hazardous substances, classified as a safety function. The ex-vessel components consist of the Interspace, Bioshield Plug, and Port Cell structures, which also accommodate many Diagnostic sub-systems.

Summary

Developing diagnostic systems for ITER involves considerable complexity and requires interdisciplinary efforts. Although some challenges are common, each system has its own, unique technical complexities that requires development of innovative solutions. The paper will be to describe how these challenges have been addressed in the design of each system.

[1] Walsh, M.; et al. / Integration of diagnostics on ITER - IEEE 26th Symposium on Fusion Engineering, 2015
[2] Costley, A.; et al. / Technological challenges of ITER diagnostics - Fusion Engineering and Design, 2005