Advances in EU In-kind contributions to Plasma Diagnostics and PI for ITER

Presented by M. Pérez Lasala and C .Colomer on behalf of the F4E Diagnostic Programme

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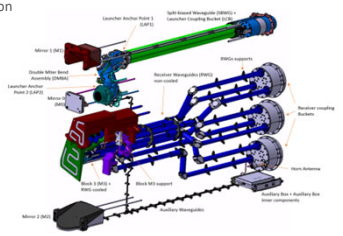
Overview

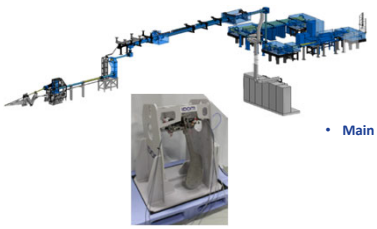
EURATOM contributions to the ITER Project include plasma and first wall diagnostics providing around a quarter of the primary measurements needed to avoid damage, to control the plasma and to explore its physics. These contributions include eight diagnostic systems, as well as six port plugs (housing a variety of diagnostics and other ITER systems) and extensive in-vessel electrical systems, providing connections to in-vessel Diagnostics. The design phase for these systems is close to completion, and many are already in manufacture.

Collective Thomson Scattering System

- **System description:**
  - Measures density and velocity distribution function of fast ions (p, D T and He3).
  - 1 MW probe (actuated by Gyrotron)
  - Eight lines of sight (7 to collect scattered radiation + 1 for subtraction of background)
- **Main challenges:**
  - Active cooling: Plasma Loads + 1 MW losses
  - Split, biased waveguide to avoid arc formation



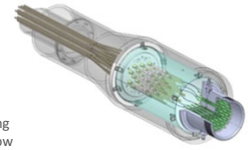
Core Plasma Thomson Scattering System

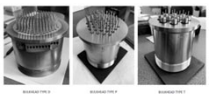


- **System description:**
  - Measures radial profile of electron temperature and density in the core plasma
  - Commercial-grade lasers: Main Nd:YAG 500 W + supp. Nd:YAG 20 W
  - 50 m transmission line from Diagnostic building until beam dump at blanket
  - Intersection detected via mirrors + fibre bundle
- **Main challenges:**
  - Minimise power density on laser windows
  - Material for beam dump (receive high power)
  - Optics design: achromatic lenses, refractive materials, active (via laser) alignment system between in-vessel and ex-vessel zones

Tokamak Services System

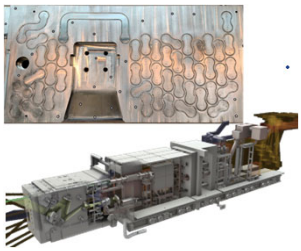
- **System description:**
  - Extensive electrical infrastructure
  - + 5000 mineral insulated (MI) cables
  - 16 electrical connectors with RH operation
  - 80 electrical feedthroughs (Nuclear Safety)
- **Main challenges:**
  - MI cables: Complex UHV terminations, copper coating to avoid electron cyclotron heating, materials with low impurities
  - Electrical connectors: Large number of MI and pin/sockets in very compact space
  - Feedthroughs composed of double vacuum Glass-To-Metal barrier -> complex manufacturing temperature profile





Diagnostic Ports Integration

- **System description:**
  - Design of 6 EU ports: In-vessel and Ex-Vessel structures, integration of diagnostics systems
  - Designs include shielding, cooling water, gas, electrical services and feedthroughs, to be installed at the primary confinement barrier
- **Main challenges:**
  - Balance of robust structure, safety assurance, and the flexibility required for integrating a wide variety of diagnostic technologies in limited space.
  - Tolerances below 50 microns for large structures
  - Maximization of shielding and weight reduction
  - Efficient cooling design



Diagnostic Pressure Gauges

- **System description:**
  - Measures pressure of particles during plasma operation
  - Wide coverage: Located at divertor cassettes, lower and equatorial ports
  - Head composed of electron source, electron acceleration grid, ion collector and thermocouple
- **Main challenges:**
  - Development of stable, long-lasting electron source
  - Specific design head (see image) that minimizes Lorentz forces (current: 15 A)
  - Expected low operational lifetime -> very high redundancy

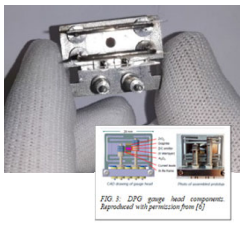
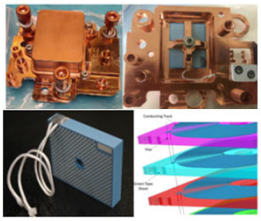


FIG 3: DPG gauge head components. Reproduced with permission from [8]

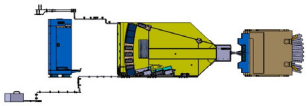
Magnetics Diagnostics

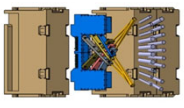
- **System description:**
  - Measure fluctuations in the local magnetic field,
  - Coils located in discrete locations inside and outside the vacuum vessel, divertor and in the TF coils
  - The absolute value of the field is determined by electronically integrating the signal in many cases
- **Main challenges:**
  - Handling fragile materials such as alumina mandrels and AlN ceramics
  - High-precision machining of thin-walled Inconel covers
  - Specialized welding techniques for sensor integration
  - Calibration processes, accounting for differential thermal expansion and delicate coil movements



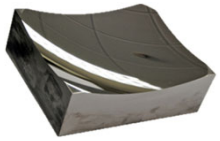
Radial Neutron Camera

- **System description:**
  - Measures neutron emissivity and alpha particles
  - Composed by a fan array of poloidal chords
  - 16 collimators located Ex-Vessel, for core plasma
  - 6 collimators located In-Vessel, for plasma edge
  - Neutron flux detectors after collimators
- **Main challenges:**
  - Sufficient sensitivity vs heavy shielding for adequate lifetime (large neutron fluence over lifetime)
  - Combination of neutron detectors:
    - In-Vessel -> single crystal CVD diamond + U238 fission chamber
    - Ex-Vessel -> plastic scintillator, He4 scintillator and single crystal CVD diamond
  - Re-alignment of ex-vessel 17t collimator with port plug

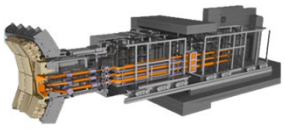




Wide-Angle Viewing System

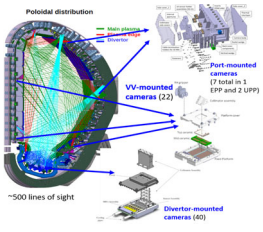


- **System description:**
  - Provides visible and IR imaging of plasma and plasma-facing components
  - Uses 15 lines of sight across 4 equatorial ports
  - Includes complex optical chains: from actively cooled mirrors in port plugs to shielded camera cabinets.
- **Main challenges:**
  - Withstand nuclear, thermal, and electromagnetic loads while maintaining optical performance
  - Integrating cooling, RF cleaning, shutters, and remote handling into compact First Mirror Units (FMUs)
  - Reliable motion compensation and radiation tolerance in piezo-actuated mirror systems over long distances

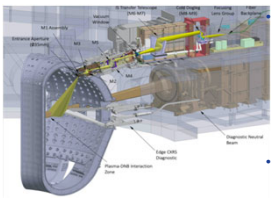


Bolometers

- **System description:**
  - Measures total plasma radiation. Sensitive from IR to X-ray
  - 467 viewing chords distributed poloidally and toroidally
  - Cameras mounted on the vacuum vessel, divertor cassettes, and port plugs
- **Main challenges:**
  - Designing radiation-hardened cameras and electronics that withstand nuclear heating, EM forces, and long cable runs
  - Sensor durability under extreme conditions: high temperature, steam exposure, and pulsed heat loads
  - Data analysis complexity due to temperature variation, neutral pressure effects, and irradiation-induced degradation



Charge Exchange Recombination Spectrometer



- **System description:**
  - Measures ion temperature, plasma rotation, and impurity concentrations
  - Complex optical path: multiple mirrors, fibre bundles, and high-resolution spectrometers
  - Includes: calibration, alignment, RF cleaning, and RH features
- **Main challenges:**
  - Achieve precise mirror alignment and optical tolerances
  - Designing components to withstand thermal and mechanical deformation from neutron/gamma heating
  - RF cleaning systems within electrical limits

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