Design of the "Magnetic Platform" for the ITER in-vessel magnetic diagnostics

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Abstract

The "In-Vessel Magnetic platform" is a subsystem of the magnetic diagnostics formed by all the components necessary for the thermo-mechanical interface of the actual magnetic sensors with the Vacuum Vessel (VV), their protection and the electrical connection to the in-vessel wiring for the transmission of the detected signal with a minimum level of noise.

Significant efforts have been dedicated to integrate the CAD model within the ITER In-Vessel configuration model, taking care of the geometrical compliance with the Blanket modules and the remote handling compatibility.

Thorough thermo-mechanical and electro-magnetic FEM analyses have been performed to assess the reliability of the system in standard and off-normal operating conditions.

Rationale of the design

Flexible and Modular → House the different types of sensors; Fit in different positions on the VV

Different requirements (often in contrast):

- **Thermo Mech.**: Mechanical attachment to the VV; Efficient heat transfer to the VV (passively cooled through thermal contact with the VV)
- **EM**: Electrical connection to the in-vessel wiring; EMI shielding from Electron Cyclotron Heating (ECH) stray radiation
- **Geom**: Compatibility with Remote Handling (RH) system; Extremely limited space available (due to the interface with other in-vessel components)

Design assessment

Good thermo-mechanical properties → Negative effects of the structures

Reduction of the frequency bandwidth of the sensors due to eddy currents

Reduced thickness or different materials

Increased thermal gradient (by neutrons and gamma interaction)

Signal noise due to thermoelectric effects (TIEMF) due to uneven temperature distribution

Conductive and thick material

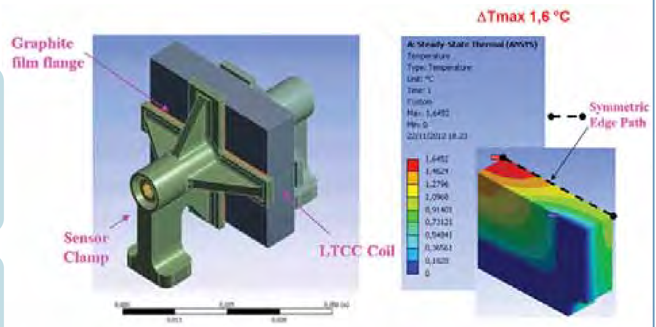
Compromise

- Several thermo-mechanical and electromagnetic FEM analyses have been performed to assess various configuration of platform design considering different geometries and materials.

Thermal analysis

Detailed analyses on sensor and clamping

Dedicated FEM analyses to investigate the thermal gradient across the LTCC sensor in order to estimate and limit the level of TIEMF noise signal

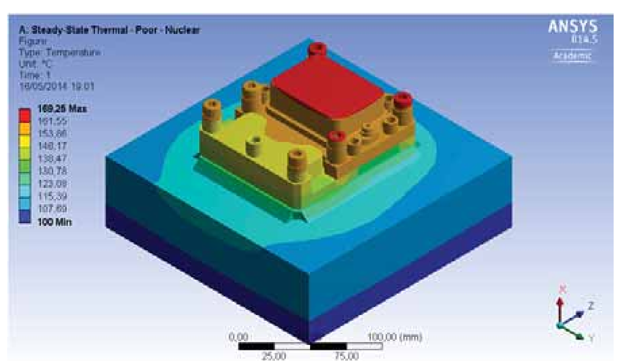


Thermal analyses on whole assembly

Aim: Base Plate optimization for minimizing the thermal gradient between Base Plate and VV in the expected operating conditions.

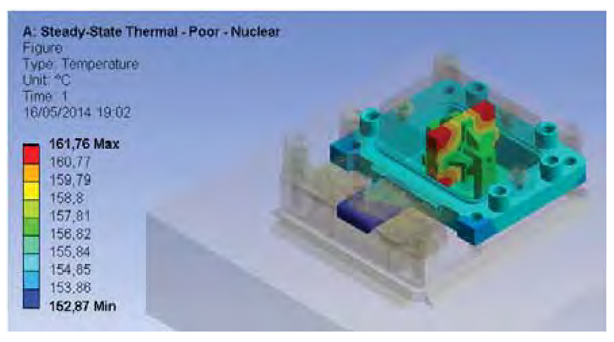
Several analyses for testing:

- different geometries of the groove;
- different welding configurations (2 or 4 welds);
- different Base Plate materials (stainless steel or copper).



Thermal assessment of the final design

- Nuclear heat loads foreseen in stainless steel (200 kW/m^3) underneath the blanket modules has been applied (with density scaling on other materials).
- Fillet welds considered, only thermal path toward the VV (water cooled at 100ºC)
- Thermal contacts between Sensor Support and Base Plate only in the 4 bolting regions, to account for the high thermal contact resistance in vacuum.



- **Temperature increase of 60ºC in the full assembly and less than 3ºC in the sensor → TIEMF well below 1 µV (acceptable noise)**

Electro-magnetic analysis

Sensor support structures shielding effect

- Functional specifications: $f_{cut\text{-}off}$ (-3 dB) > 15 kHz
- 3D harmonic magnetic FEM analyses

1st analysis set

Aim: to define shape and materials of sensor clamp brackets

Results: 'cross shaped support' made of copper

- minimized EM shielding effect
- still adequate thermal conductance (not achievable with SS)

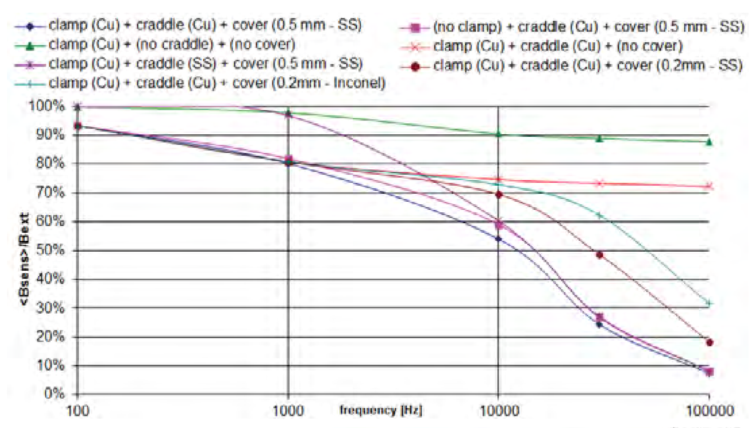
2nd analysis set

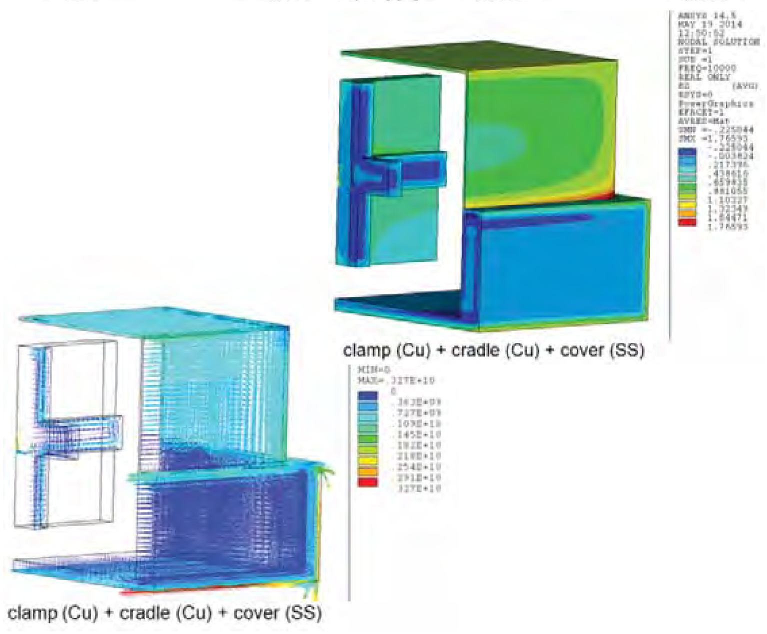
Aim: to assess the EM shielding effect of the whole metallic structures around the sensor: clamp bracket, cradle and ECH shielding cover

Model: 1/4 of sensor assembly (exploits 2 symmetry planes)

Results: ECH shield dramatically reduces $f_{cut\text{-}off}$ << 10 kHz; required sensor cover modification:

- 0.2 mm thickness SS cover
- or "metal coated ceramic" as for HF sensors.





Sensor location

Several hundreds of magnetic sensors are required in ITER for machine protection, plasma control, equilibrium reconstruction and physics studies.

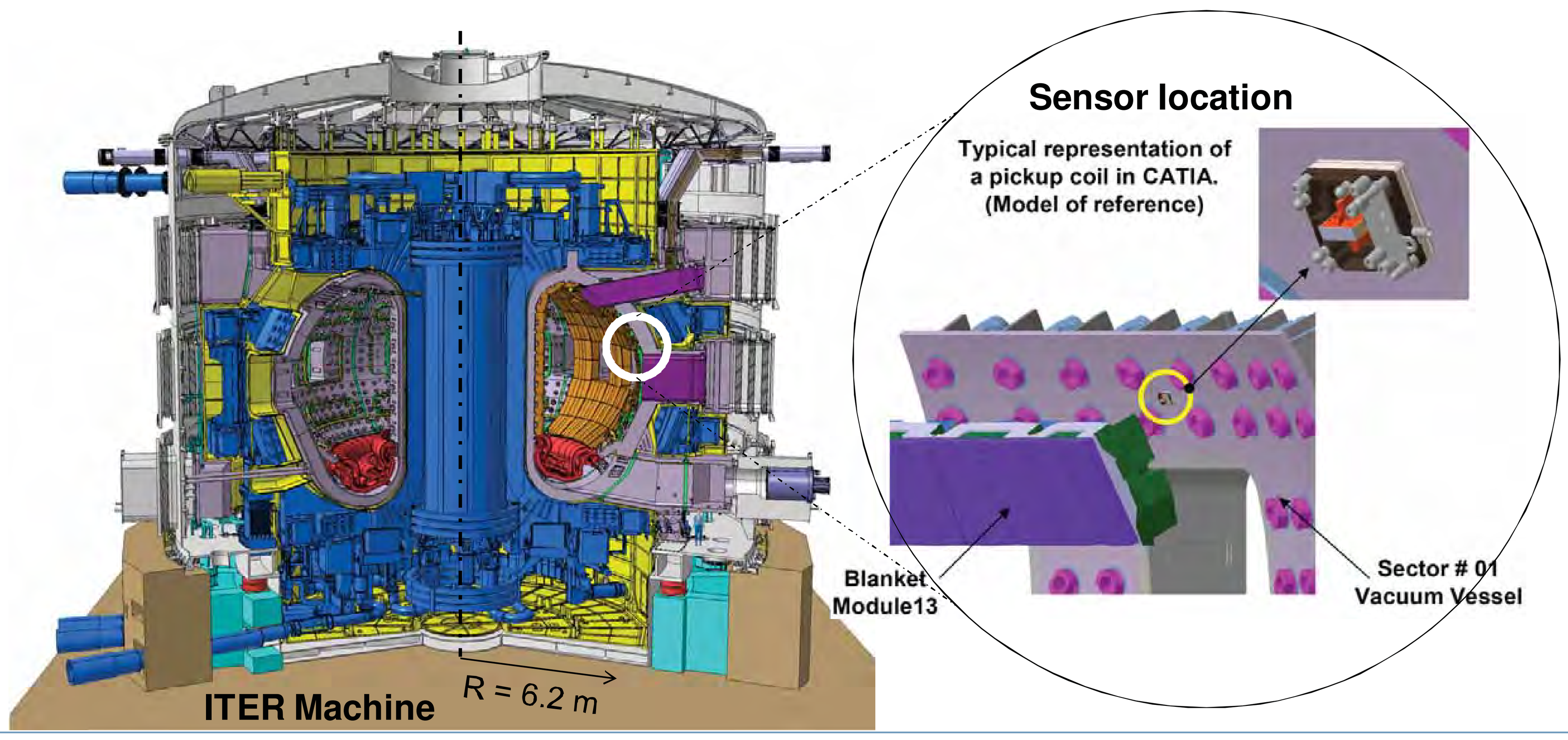
Located within the ITER VV, in a hostile environment characterized by severe neutron irradiation and plasma heat loads strongly affecting their reliability and durability.

Attached to the inner surface of the VV, behind Blanket modules or divertor cassettes, through a connection system which allows a potential replacement by a suitable RH system.

The "**In-Vessel Magnetic Platform**" is a component shared by a subset of the ITER in-vessel discrete magnetic sensors: Inner Tangential Coils (55.AA), Inner Normal Coils (55.AB), Toroidal Coils (55.AC) and High Frequency Sensors (55.AJ).

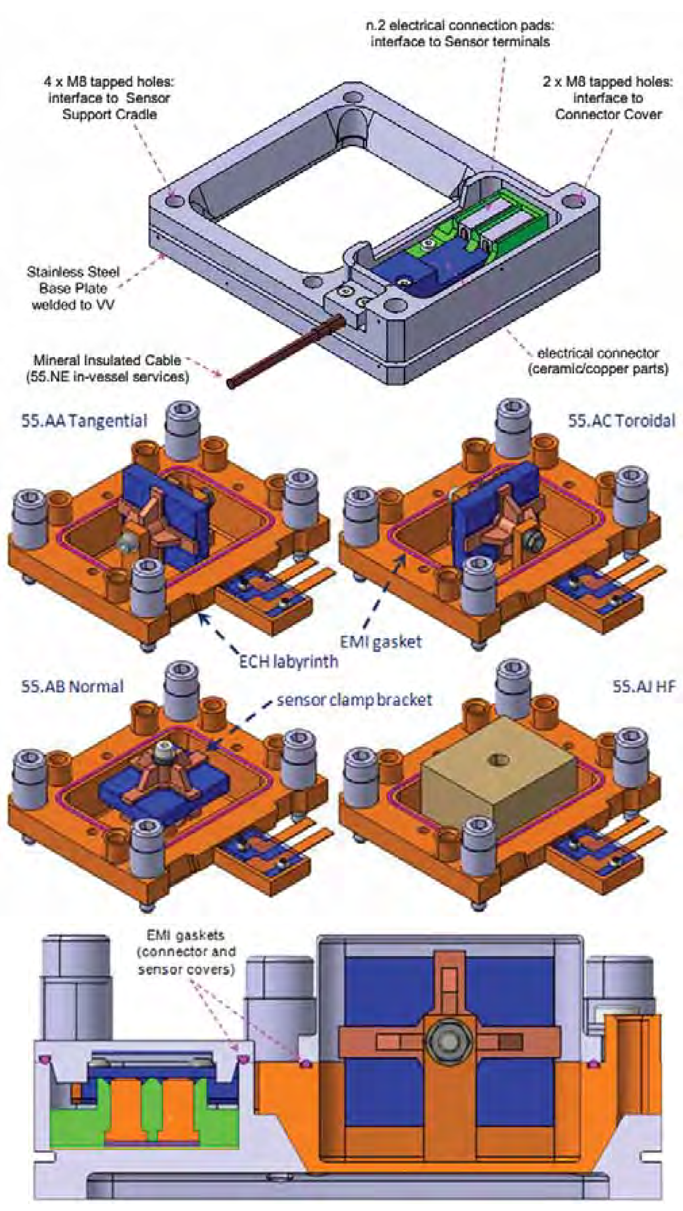
The platform provides two main functions:

- mechanical support within the VV;
- electrical connection to the in-vessel wiring for the transmission of the measurement signal.



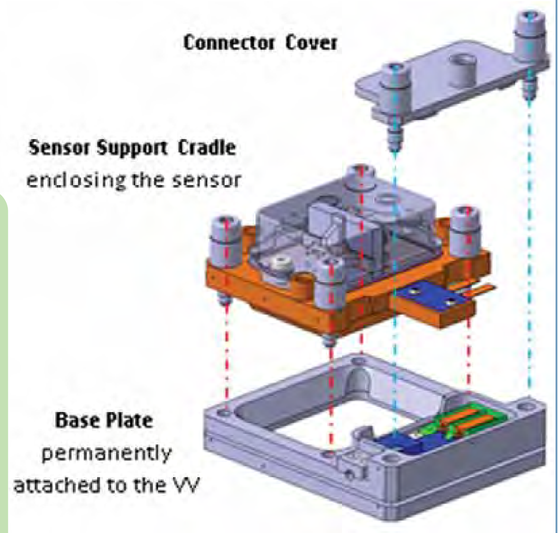
Design description

Replacement by RH system → Design composed of three subsystems



Base Plate

- permanently attached to the VV (TIG fillet weld all around external perimeter)
- thermo-mechanical attachment of the sensor cradle to the VV surface
- electrical connection of the sensor to the in-vessel wiring



Magnetic platform assembly (dimensions: 120 x 100 x 50 mm)

Sensor Support Cradle

- houses the sensor
- allows its replacement by proper RH features
- made of copper to provide good thermal path (to limit over-temperature within the sensor due to nuclear heating)
- different configurations for different kinds of sensor
- specific features to prevent penetration of ECH stray radiation (labyrinth shaped interfaces and EMI shielding gaskets)
- suitable venting holes guarantee a proper vacuum pumping.

Connector Cover

- 3 mm thick Stainless Steel plate
- protects the electrical connector
- allows its replacement by proper RH features
- specific features prevent the penetration of ECH stray radiation

Structural analysis

Base Plate structural assessment (normal and off normal operation)

Boundary conditions:

- gravity and seismic loads negligible (according to specifications);
- only worst EM forces, induced during fast discharge events, (max = 7.1 kN, assessed with proper EM calculations), and thermal loads considered.

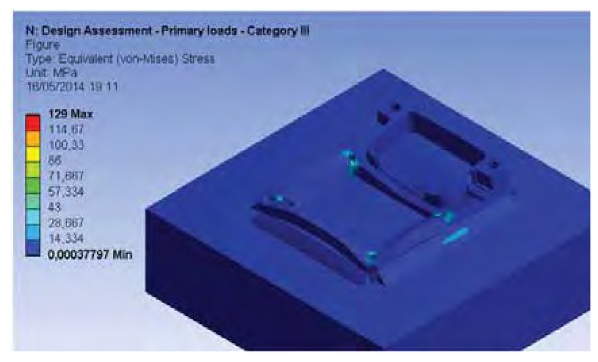
Assessment (according to the French nuclear norm RCC-MR):

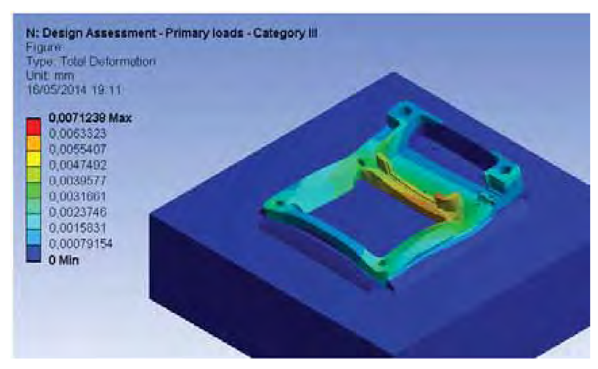
- different load combinations classified;
- components verified against plastic collapse, ratcheting and fatigue.

Results: welds are the most critical parts:

- additional safety factors and strong fatigue life requirements limit the allowable stress in the welds (decided by ITER Organization);
- allowed primary membrane stress fixed at 14.1 MPa (1/10 of AISI 316L base material at 150ºC) for fillet welds on VV (full inspection testing not possible);
- fatigue (nuclear heating secondary stress has to be considered) is not satisfied.

- Redesign of the Base Plate weld zone and the selection of full penetration welds, which allow higher allowable stress, is presently under consideration.





Acknowledgments

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Conclusions

The preliminary design of the in-vessel magnetic platform to house different types of magnetic sensors has been optimized by means of FEM electro-magnetic and thermo-mechanical analyses. The design had to cope also with narrow space and remote handling compatibility requirements for the installation of the sensors between the blanket and the vacuum vessel of ITER. Modification of the mechanical connection to the vacuum vessel is under study to comply with fatigue requirements of the welded joint.