Design Finalization and Development of Reconstruction Algorithms for the Operational Instrumentation of the Internal Components

Call For Nomination (CFN)

Purpose

According to the ITER Project Requirements, ITER systems shall contain instrumentation to measure all parameters that may affect their system availability or which may predict failures or indicate the need of maintenance. To meet this top level requirement, the internal components of the ITER machine (Divertor and Blanket Systems) will be equipped with a set of operational instrumentation.

This contract has two main purposes:

1) to finalize the design of the operational instrumentation of the internal components (Blanket and Divertor) via defining the exact number, type and locations of the various sensors. This optimization is aimed at minimizing the error during the reconstruction of the actual loads within the constraints of the total number of sensors that can be accommodated;
2) to develop the reconstruction algorithms to calculate the actual loads acting during the operation on the internal components starting from the measured experimental data.

Background

The ITER Project

The ITER project aims to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes and to gain the knowledge necessary for the design of the next-stage device, DEMO, or the DEMOnstration fusion power plant.

ITER is a joint international research and development project for which initial construction activities have started.

The seven Members of the ITER Organization are the European Union, Japan, The People's Republic of China, India, the Republic of Korea, the Russian Federation and the USA.

ITER is being constructed in Europe, at St Paul Les Durance, in southern France, where the IO has its headquarters.

As illustrated in Fig. 1, the machine consists of:

- the cryostat, which maintains the entire machine in a vacuum to thermally insulate the cryogenically cooled, superconducting magnets from the normal atmosphere,
- thermal shields, which further thermally insulate the magnets;
- the assembly of 48 superconducting magnets, which confine and heat the plasma;
- the Vacuum Vessel, a doughnut shaped chamber located at the heart of the machine and containing the plasma under Ultra High Vacuum;
- The Blanket System, which faces the thermonuclear plasma and remove most of the heat loads and radiation coming from it. It consists of 440 Blanket Modules, actively cooled by pressurised water. Each Blanket Module consists of a Shield Block, made of austenitic steel, and a plasma facing panel, the so-called First Wall.
- The Divertor, which is located at the bottom of the vacuum chamber and which also faces the thermonuclear plasma. It removes most of the impurities coming from it. It consists of 54 Cassette Assemblies, actively cooled by pressurised water. Each Cassette Assembly consists of a Cassette Body, made of austenitic steel, and three plasma facing components, the so-called Inner and Outer Targets and the Dome.

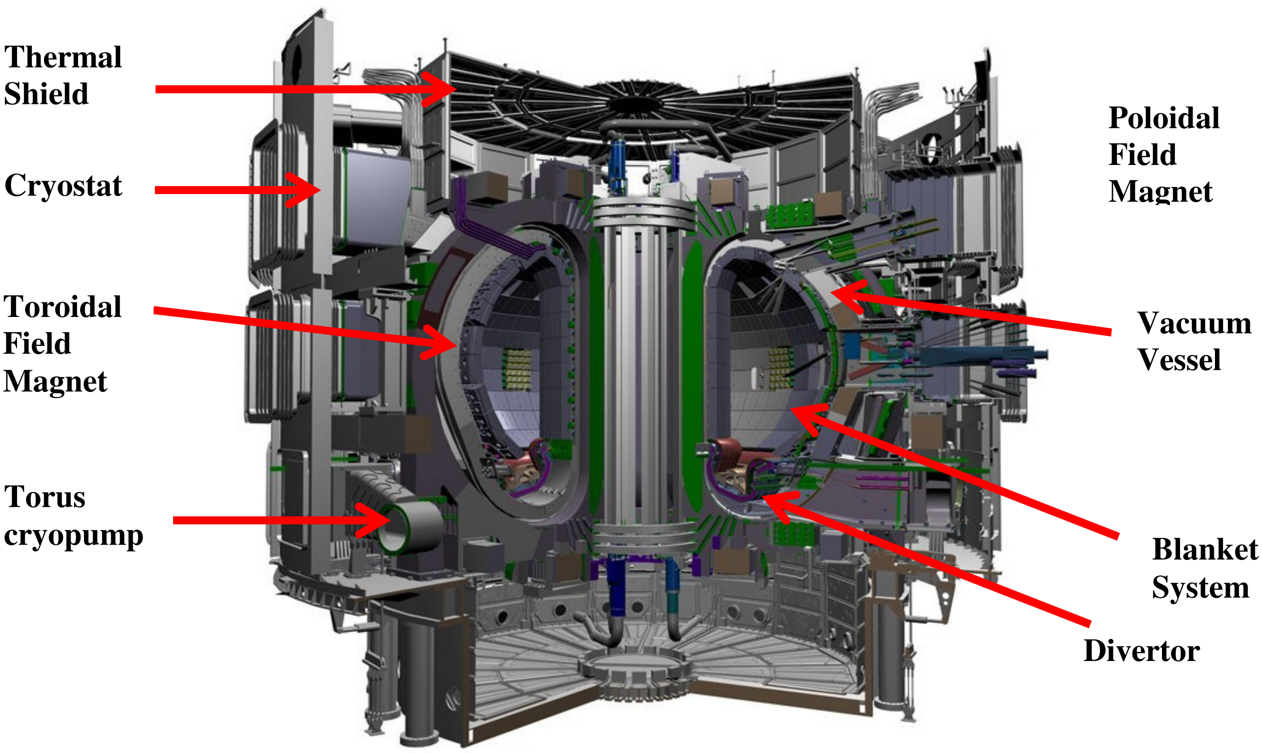

Figure 1 The ITER Machine and Major Components

<u>Electromagnetic loads</u>

During the ITER operation, the plasma can face an off-normal termination, which results in transient electromagnetic (EM) loads.

EM analysis aims at calculating the induced currents, namely:

- **Eddy currents**, induced by the mechanism of conservation of the magnetic fluxes crossing conductive parts.
- **Halo current,** induced by the mechanism of conservation of the toroidal magnetic flux in the plasma core region. It is closed via a conductive loop formed partly by the conductive structures and partly by the periphery of the plasma layer (a layer with "open" magnetic lines which intercepts plasma facing components).

These currents interact with the toroidal and poloidal magnetic field thus generating EM forces.

The highest EM loads are caused by two kinds of off-normal terminations of the plasma pulse: **Major Disruptions** (MDs) and **Vertical Displacement Events** (VDEs).

- A **MD** consists in an off-normal termination of plasma pulse initiated by a loss of energy confinement, resulting in a thermal quench and followed by a plasma current decay, with the corresponding vertical drift and compression of the plasma core.
- A **VDE** consists in an off-normal termination of plasma pulse initiated by a failure of vertical position control, followed by a vertical drift of the plasma. Then with transition to limiter configuration, this leads to the thermal quench and is followed by a plasma current decay, with a further vertical drift and compression of the plasma core.

The ITER project bases simulation of plasma evolution with DINA code. DINA delivers waveforms (time dependent functions) of many plasma parameters, time dependent profiles of toroidal and poloidal plasma current densities and time dependent poloidal distribution of halo current intercepting the plasma-facing components.
DINA simulates axially symmetric (2-D) plasma evolution. In reality, during the last phases of VDEs, the plasma tends to lose axial symmetry being distorted in a kink-mode, and this mode tends to rotate. This phenomenon distorts axial symmetry of halo current distribution and adds a cyclic component to halo related EM loads.

<u>Blanket and Divertor Operation Instrumentation</u>

The top level requirement of the Blanket and Divertor Operation Instrumentation (BOI/DOI) is to measure all parameters that may affect those systems availability or which may predict failures or indicate the need of maintenance. This is achieved by:

- Monitoring of the EM, mechanical and temperature fields of structural components.
- Measuring of experimental data required for the validation of the numerical models during ITER operation.
- Estimation of EM loads acting on the Blanket and Divertor structural components during MDs/VDEs via the EM and mechanical experimental data.
- Supply Central Interlock System (CIS) diagnostic data for performing interlock actions via CIS and other Plant Interlock Systems.

BOI/DOI consists of 3 main systems:

1) Electromagnetic Monitoring System (EMS), which includes:
    a. Rogowski coils.
    b. Magnetic flux sensors.
2) Mechanical Monitoring System (MMS), which includes:
    c. Strain sensors.
    d. Linear Displacement Sensors (LDS).
3) Temperature Monitoring System (TMS), which includes:
    e. Thermocouples.
    f. Fiber Optic Temperature sensors.

The main functions of the EMS are:

- ➢ Assessment of EM loads acting on the Blanket and Divertor structural components.
- ➢ Monitoring of the eddy/halo currents of Blanket and Divertor structural components.
- ➢ Collecting of information required for the validation of EM numerical models.

The main functions of the MMS are:

- ➢ Monitoring of the stress/strain fields, displacements and accelerations of Blanket and Divertor structural components.
- ➢ Estimation of EM loads in Blanket and Divertor structural components during plasma disruptions and VDEs.
- ➢ Validation of numerical mechanical models of the Blanket and Divertor.
- ➢ MMS should also be used as part of a system to estimate residual life-time and predict possible damages.

The main functions of the TMS are:

- ➢ Monitoring of temperature fields of Blanket and Divertor structural components.
- ➢ Validation of numerical thermal models of Blanket and Divertor.

Scope of work

The first main purpose of this contract is the definition of the optimum number, type and location of the sensors for the operational instrumentation of the Divertor and Blanket systems. The optimization shall be aimed at minimizing the error during the reconstruction of the actual loads within the constraints of the total number of sensors that can be accommodated.
The second main purpose of this contract is also the development of the reconstruction algorithms to calculate the actual loads acting during the operation on the internal components starting from the measured experimental data.

The following input data will be supplied by IO:

- The 3D CAD models (in CATIA v5 format or STEP file) of specific components of the Blanket and Divertor Systems;
- The type, number and locations of the sensors of the BOI/DOI on the basis of the existing Conceptual Design, as well as the place for location of additional set of “virtual sensors”, which may be considered during the study;
- The DINA input files, which are required for the EM analysis of the EM scenarios.

On the basis of the above information, the Contractor will be requested to perform the following steps:

1) Calculate the resulting EM loads as well as the dynamic structural response of the specific components of the Blanket and Divertor Systems. The main purposes of this 3D global EM numerical analysis are:
    (a) The calculation of induced currents and corresponding EM loads, including integral forces and moments;
    (b) On the basis of the EM loads, a global static and dynamic mechanical analysis is performed;
    (c) On the basis of the global static and dynamic mechanical analysis, a local detailed stress analysis is performed;

2) The calculation of “virtual measurements” is carried out from the existing set of BOI/DOI sensors and additional set of “virtual sensors”: Rogowski coils, Magnetic Flux Loops and three components of either local strain, or acceleration, or displacement in the location of each sensor.

3) Incorporate the BOI/DOI sensors and “virtual sensors” into a numerical model, and develop reconstruction algorithms of the generating EM loads with artificially and stochastically added noise.

4) Perform a systematic statistical comparison of loads reconstructed with parametric variation of inputs at step 3 vs. those resulting directly from step 2. This is to evaluate the "ideally achievable" precision of the developed reconstruction algorithms.

The final outcome of this contract is a definitive conclusion on the type, number and locations of the sensors, as well as the development of suitable algorithms to reconstruct the actual loads, which have generated the measured experimental data via the selected sensors.

Tentatively, the study will be carried out with the following variables:

a) Two reconstruction algorithms to be developed and compared;
b) Two variants of plasma EM events;
c) Four set of sensor data used as input for reconstruction;
d) Four levels of artificially introduced measurement errors (noise);
e) One or more different geometries of the Blanket and Divertor components to be analysed.

The work is anticipated to be performed in two Phases of about 1.5 year duration each, and focussing on the Divertor and Blanket System, respectively.

Experience Requirements

The companies shall have adequate experience in the following areas:

- Experience in Electromagnetic analysis to assess the structural implications of the off-normal plasma conditions (i.e. plasma disruptions and Vertical Displacement Events). More specifically, eddy and halo currents are developed in the tokamak components. These currents interact with the toroidal and poloidal magnetic field thus generating large electro-magnetic forces. Eddy and halo currents in the structures shall be calculated on the basis of inputs provided by the DINA code.

- Expertise in using ABAQUS or ANSYS software for thermal (steady state and transient) and mechanical structural analysis using finite element method technique.

- Expertise in using CATIA V5 CAD software, or STEP files as an input data for the development of the analytical models.

- Expertise in reconstruction algorithms for ill-posed inverse problems.

- Expertise in statistical analysis.

- Expertise in design and implementation of EM, thermal and mechanical instrumentation, including design, as well as signal conditioning and data acquisition.

Tentative Timetable

The pre-qualification phase will be carried out together with the tender evaluation.
The tentative timetable is as follows:

Tender submission	August 2017 till October 2017
Tender Evaluation	November 2017
Contract placement	December 2017
Completion	December 2020

Candidature

Participation is open to all legal persons participating either individually or in a grouping (consortium) which is established in an ITER Member State. A legal person cannot participate individually or as a consortium partner in more than one application or tender. A consortium may be a permanent, legally-established grouping or a grouping, which has been constituted informally for a specific tender procedure. All members of a consortium (i.e. the leader and all other members) are jointly and severally liable to the ITER Organization.

The consortium groupings shall be presented at the pre-qualification stage. The tenderer's composition cannot be modified without the approval of the ITER Organization after the pre-qualification.

Legal entities belonging to the same legal grouping are allowed to participate separately if they are able to demonstrate independent technical and financial capacities. Candidates (individual or consortium) must comply with the selection criteria. The IO reserves the right to disregard duplicated reference projects and may exclude such legal entities from the pre-qualification procedure.