Design of an in-vessel Penning ion gauge for local neutral pressure measurement in KSTAR tungsten cassette module

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Topics

E. Diagnostics

Communication type

Poster

Abstract

A newly designed in-vessel Penning ion gauge (PIG) has been developed to measure local neutral pressure dynamics beneath the tungsten cassette module (TCM) in the Korea Superconducting Tokamak Advanced Research (KSTAR) device. In-vessel neutral pressure diagnostics in fusion reactors are essential for real-time density feed-back control through particle balance analysis, vacuum system design and testing, discharge cleaning optimization, and impurity seeding experiments for detachment studies. Conventional gauges located ex-vessel to minimize perturbations to the tokamak magnetic configuration introduce potential misinterpretations in experimental analysis when measuring neutral by-products generated during operation, particularly in the observation and control of transient phenomena. To address this limitation, a PIG has been designed for the first time in KSTAR to enable temporally resolved neutral pressure measurements at localized regions within the vacuum vessel. The reliability of the gauge is verified through preliminary operation tests conducted in the Versatile Experimental Spherical Torus (VEST). Additionally, Mol-flow+ simulations are performed to predict the gauge response to local pressure variations in the divertor region, demonstrating its validity and short temporal response. Following successful validation, PIGs are installed at tree strategic locations within the full-tungsten KSTAR divertor structure: the inner divertor target, the outer divertor target, and private flux region (PFR).

Hall sensor measurement in the KSTAR tokamak

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Topics

E. Diagnostics

Communication type

Poster

Abstract

There was always the nonlinear integrating drift present in the signals of the inductive magnetic sensors used for the plasma control in long-pulsed plasmas with the duration of longer than 30 s in the KSTAR tokamak. Especially, a large nonlinear drift appeared in the signal of the sensor located at the outer midplane (OMP) side, which was mostly caused by the heat-up of the sensor itself due to the radiation from plasma column because the sensor was opened to the plasma at the OMP side [1]. Thus, there was an activity for finding a method for compensating the nonlinear drift in the signal during the long-pulsed plasmas. In parallel with the activity, we tried to apply the method by using Hall sensors for the magnetic measurement in the KSTAR. Considerable progress on the research and development of the Hall sensors have been carried out in the Institute of Plasma Physics (IPP) of the Czech Academy of Science (CAS) for applying them to the magnetic measurements in the future machines such as the ITER and DEMO [2, 3]. Several Hall sensors were provided by the IPP CAS as the international collaboration, so the performance test of the Hall sensors was carried out during the experimental campaign in the KSTAR. In addition, the adaptability of the sensor fusion technique applied to the synthetic magnetic data of the inductive sensor and Hall sensor [4] on the real magnetic measurements with the two sensors was examined for resolving the nonlinear drift issue during the long-pulsed plasma in the KSTAR. In this work, the issue of the nonlinear drift in the magnetic measurement by using the inductive sensor for the long-pulsed plasma will be described. Secondly, the results from the Hall sensor measurement during typical vacuum and plasma shots will be presented. Finally, the sensor fusion technique for resolving the nonlinear drift issue in the magnetic measurement during the long-pulsed plasma will be discussed.

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Keywords: Nonlinear integrating drift, Hall sensor measurement, Sensor fusion technique, Long-pulsed plasma, KSTAR tokamak

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#12652

Design development and feasibility investigation for the MITICA diagnostic calorimeter

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The full-size prototype of the ITER Heating Neutral Beam Injector MITICA (Megavolt ITER Injector Concept Advancement) is presently under construction at the Consorzio RFX (Padova, Italy). The injector is designed to produce, accelerate and neutralize high energy, up to 1 MeV, and high power, up to 16.5 MW, neutral particle beams from H− or D−. One of the most challenging task is to obtain a uniform production of the negative ions over the 1280 apertures from which the beam is extracted. In view of the future operation in MITICA, to safely operate the facility and to derive indications for its design improvements, it is needed to obtain the vertical beam current profile and to measure the beam optics detecting the actual single-beamlet aiming. For these reasons, a new movable calorimeter, capable of intercepting a column of ion beams, is foreseen to be installed in MITICA. The diagnostic tool, made of graphite tiles looked from the beam-impinging side by an IR camera, will be used in short pulses operation providing a spatial resolution of 0.5 mrad in beamlet aiming accuracy.

This work presents the initial feasibility studies for the conceptual design of this calorimeter and its integration with the ion source, leading to the definition of the optimal configuration as a compromise between power density deposition and spatial resolution. Beam simulations and beam–graphite interaction analyses were performed to identify the optimal calorimeter layout. Specific beam scenarios were defined and simulated to quantify the diagnostic capability of the proposed design. Thermomechanical simulations were used to maximize the safety engineering margins, and the requirements for the IR imaging system were also considered for the various configurations. Different calorimeter positions and orientations were studied to define the optimal distance from the source, balancing the possibility of removing the system from the beam trajectory with the diagnostic requirements, while satisfying the geometrical constraints of the MITICA experiment. These results provide the basis for the detailed engineering design and implementation of the diagnostic system for its deployment in the initial MITICA beam operation phase.

#12823

Comparative Evaluation of Gamma Detection Modules for Precise Neutron Fluence Measurement in ITER NAS

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The ITER Neutron Activation System (NAS) determines neutron fluence by measuring gamma rays emitted from irradiated activation foils and subsequently back-calculating the incident neutron flux. For 14.1 MeV DT neutrons, materials such as Si, Al, Fe, Cu, and Ti are considered as activation foils in neutron diagnostics for ITER. Since the induced radionuclides from these foils emit different energies across the 511-1778 keV and have different half-lives, the most appropriate foil must be selected depending on the expected irradiation scenario in ITER. Accordingly, the gamma-ray detection module must be optimized for this energy range. Detectors for gamma-ray spectroscopy are broadly categorized into semiconductor and scintillation detectors. Among semiconductor detectors, High-purity germanium (HPGe) offers superior energy resolution but requires cryogenic cooling, whereas silicon drift detectors (SDD) are limited in high-energy gamma detection due to their small thickness and low atomic number. Room-temperature cadmium zinc telluride (CZT) detectors provide good spectroscopic performance, yet their high cost and limited scalability make large-area deployment practically difficult. By contrast, scintillation detectors enable large-area, cost-effective fabrication and high detection efficiency for high-energy gamma rays, though they exhibit lower energy resolution due to their indirect detection mechanism. Here, we comparatively evaluate neutron fluence measurement accuracy using semiconductor detectors (HPGe and CZT) and scintillation detectors including Cs3Cu2I5, LaBr3(Ce), CeBr3, GAGG, and NaI(Tl). Using HPGe as the reference standard, we identify the most suitable detector material for an ITER-optimized, cost-effective mid- to low-resolution NAS gamma detection module.

#12827

Design, calibration and performance of a Hybrid Al-Cu Triple-GEM detector with remote front-end electronics for fusion devices

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Soft X-ray imaging diagnostics operating in the 2–30 keV range and based on Gas Electron Multiplier (GEM) detectors have been successfully employed on several tokamaks, providing noise-free 2D measurements with high sensitivity, spatial and temporal resolution. With suitable front-end electronics, GEM-based cameras can also provide energy-resolved measurements, enabling spectroscopic capabilities. Future fusion devices, characterized by intense neutron irradiation and the need for an extended X-ray energy range, require detector concepts that preserve spectroscopic performance while ensuring diagnostic reliability. Neutron irradiation tests performed at the Frascati Neutron Generator facility with 14 MeV neutrons confirm that the GEM detector remains operational at fluxes exceeding 10^7 n/cm^2•s, while front-end electronics mounted on the back of the detector fail at significantly lower fluxes, of the order of 10^5 n/cm^2•s.

In this contribution, we report on the design, calibration, and performance of a hybrid Al-Cu Triple-GEM detector equipped with remotely located front-end electronics. The detector architecture combines a hybrid GEM stack of two aluminum foils and one copper foil, aimed at mitigating X-ray-induced background from the copper layers on the GEM foils, with a PCB readout featuring a 16×16 pad matrix (6×6 mm2 per pad). A side-window geometry enables absorption profile measurements across the full gas depth and supports operation at higher photon energies, up to 50 keV using an Ar-CO2 mixture and higher with heavier noble gases such as xenon or krypton.

The readout chain is based on 64D GEMINI ASICs connected to the detector via micro-coaxial cables (20–200 cm), allowing the front-end electronics to be displaced outside the highest radiation region and shielded efficiently. A dedicated performance study was conducted using a pulse generator to simulate X-ray interactions. Threshold optimization and cable-length effects on pulse shape were investigated, showing that stable operation is preserved up to 1–2 m cable length with only moderate signal broadening. Signal degradation was quantified using the ratio FWHM/ToTmax, where ToT (Time-over-Threshold) provides an estimate of the collected charge, remaining ≤3% for cables ≤100 cm and increasing to 4% at 200 cm. These results were validated using 5.9 keV X-rays from a 55Fe source, in terms of spectroscopic capability and image uniformity. In addition, a pad-by-pad calibration procedure was implemented using X-ray fluorescence emission lines from multiple targets, enabling a quantitative comparison of calibration parameters in both head-on and side-on configurations. Results will be presented for both configurations. Part of this work was supported by ITER.

Experimental study of the distortion of the electron velocity distribution function by Thomson scattering system

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Thomson scattering systems measure electron temperature under the assumption that the electron velocity distribution is pure, single Maxwellian distribution. However, recently, electron temperature anisotropy and non-Maxwellian distribution of electrons have been observed in LHD experiments by spectroscopic diagnostics [1][2]. Thomson scattering diagnostic system is also considered one of good diagnostic tools for the study of the distortion of the electron velocity distribution from a pure Maxwellian distribution. The purpose will provide useful information for plasma transport studies toward fusion reactor research.
In the original design of LHD Thomson scattering system, Thomson scattering spectra are measured by polychromators with five wavelength channels to determine electron temperature. In addition to the five-channel polychromators, we developed and installed polychromators with twelve wavelength channels. [3][4] They are optimized for searching non-Maxwellian distribution around Te = 3 - 5 keV. We discuss the agreement and disagreement between theoretical estimation that assumes a pure Maxwellian distribution and experimental results obtained in the 2023 - 2025 LHD experiment campaigns.

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In-situ assessment of the emissivity of ITER-grade plasma facing component in the WEST lower divertor

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Infrared (IR) thermography is widely used in fusion research to study the heat load distribution on the plasma facing components (PFC) as well as ensuring their protections. To these ends, assessing the emissivity of tungsten (W) components is necessary to derive accurate surface temperature from IR systems. The W emissivity is low and dependent on various parameters such as wavelength, temperature, and surface state. During WEST phase 1 (2017 to 2021) a first in-situ method has been developed to assess the emissivity of few divertor PFCs. This method took advantage of the divertor temperature increase after successive plasma experiments due to the inertial behavior of the WEST phase 1 PFC (uncooled W-coated graphite PFC). With this method the PFC emissivity evolution during the 2019 campaign has been monitored for a wide range of experiments. The PFC emissivity evolved from 0.12 to 0.6, compared to the pristine emissivity of ~0.12. In 2021, the W-coated graphite components have been removed to equip the divertor with ITER-grade actively cooled components (WEST phase 2). This change meant that emissivity could no longer be measured as in phase 1, due to the active cooling of the components.

In 2024 the cooling loop of the lower divertor has been modified to be able to modify the temperature of two sectors (among twelve) of the lower divertor PFC, without modification of the other cooling loops. The paper reports on the modification of the cooling loops, the emissivity calculation and the measurement obtained during three campaigns. During the campaigns C10 (2024) and C11 (beginning of 2025), the emissivity pattern showed, as expected, emissivity ranging from 0.1 to 0.9 with low emissivity in the strike line location and high emissivity in the thick deposit region of the high field side region. Between C11 and C12 (end of 2025) the whole divertor has been cleaned with a laser cleaning method removing all the deposits at the surface of the ITER-grade PFCs. The emissivity measurement performed before C12 showed emissivity ranging from 0.1 to 0.2 in agreement with clean W surface. Finally, the emissivity has been monitored along the C12 campaign which has been devoted to a high fluence campaign in low Te regime (as foreseen in ITER). The emissivity pattern evolves also in this regime, where the W erosion in the divertor is drastically reduced, with a drastically different pattern showing high emissivity (>0.6) even in the strike line region.

Multi-Physics Simulations for Advanced Thermal Protection of Tokamaks: Development and Experimental Validation of the IMPACT Platform

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Wall temperature monitoring in fully metallic fusion devices presents significant challenges due to the highly reflective environment and the time-varying, heterogeneous surface properties of plasma-facing components (PFCs). To overcome these difficulties, we introduce IMPACT, a multi-physics simulation platform that integrates heat flux (HF) deposition modeling—which accounts for both conductive power from high-energy particles and radiative plasma emissions—with the generation of high-fidelity synthetic infrared (IR) images.

Developed in the Eurofusion Digital Twin Environment (DTE) framework, IMPACT pursues two key objectives:
(1) Supporting pulse preparation and design optimization/validation by providing 3D heat flux distributions and surface temperature maps for predefined plasma scenarios;
(2) Enabling advanced IR diagnostics and PFC analysis through the simulation of physically accurate IR images.

This paper describes IMPACT's modular architecture and highlights its computational optimizations, which include GPU hardware acceleration (using an NVIDIA A40) and CPU parallelization. These improvements have achieved a >100× speedup, reducing heat load estimation time from 10 hours to just a few minutes and enabling the simulation of high-resolution IR images in under 5 seconds—a capability that is essential for the generation of large-scale synthetic datasets used to train Machine Learning (ML) models for measurement inversion.

A particular focus is placed on validation and verification to ensure the software's reliability and accuracy. The validation process follows a two-step approach:
(1) The platform is first validated against the Magryt experimental facility, a dedicated testbed that replicates tokamak surface temperature measurement conditions under controlled laboratory settings. Benchmarking results demonstrate a deviation of less than 10% in predicted apparent temperature, while accounting for the angular dependency of emissivity. This quantitative agreement validates both the photon transport model and the optical models of reflectance and emissivity.
(2) In-situ validation is conducted using the WEST tokamak: IMPACT's accelerated workflow allows manual adjustments to be made for comparing experimental and simulated data, and so the identification of reflection patterns. Although manual tuning is currently the standard approach (with automation efforts underway), the multiphysics coupling has enhanced simulation fidelity. Further work is still required to refine other heat source models (e.g., ripple losses) and thermal models in order to further reduce uncertainties.

By combining computational efficiency with physics-based accuracy, IMPACT enables near-real-time simulations that effectively bridge experimental observations and predictive modeling. This integrated approach enhances decision-making processes during operations and strengthens PFC protection strategies.

#12886

Characterization of Runaway Electrons and their impact on tungsten PFCs on WEST

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Plasma current disruptions in tokamaks can generate highly energetic electrons, in the range of MeV, named Runaway Electrons (RE) which induce, upon impact on the walls, severe damage to the plasma facing components. Since REs can carry a large fraction of the initial plasma current, their effects in
ITER, where the plasma current can reach 15MA, are of critical importance. As the new ITER base line [1] foresees tungsten as the first wall material, the effects of REs and their damage potential must be addressed.
In order to investigate the behaviour of REs, dedicated experiments have been conducted on WEST, which is equipped with full tungsten PFCs (divertors and limiters) similar to the ITER configuration, aiming at the characterization of the RE beam and its impact on the tungsten wall. In this respect, deliberate disruptions were provoked in discharges with plasma current in the range of 300-650 kA in order to produce and control a RE beam lasting up to 1 second. The electrons in the RE beam emit synchrotron radiation, which was observed in a tangential view with a fast-visible camera at 2 kHz frequency and with a multi-spectral infrared camera in the range of 1.5-5 μm. Additionally, a visible-infrared spectrometer (REIS) has been used to analyse the spectrum emitted by the RE beam. The synchrotron emission is simulated with the SOFT code [2] and compared to the IR spectral images to derive the pitch angle and the electron mean energy assuming a monoenergetic RE beam. Good match between simulations and measurements is obtained with 0.15- 0.3 rad pitch angles and 10-20 MeV RE energy. The RE beam was finally guided toward a dedicated bulk tungsten tile of the inner limiter equipped with two thermocouples allowing the determination of the energy deposited during the impact. Severe damage was observed with tungsten melting and projection of melt debris over a circle of about 5 cm radius and an excavated depth in the range of mm. The loaded energy estimated from the TC measurements without cooling due to melting is about 50 kJ. The impact duration estimated with the fast-visible camera is about 3ms. These values are used for predictive simulations of the failure mechanisms in tungsten PFCs under ITER conditions using a dedicated numerical workflow (GEANT4 code to compute the energy loading in the tungsten and LS-DYNA code to evaluate the mechanical stresses and identify the failure mechanism).

An Adaptive Modular Framework for Robust Diagnostic Reconstruction and Plasma State Monitoring

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The operational safety of future fusion devices like ITER and DEMO demands a paradigm shift in how we handle diagnostic data, moving away from rigid traditional models that collapse during hardware malfunctions or signal gaps. In this work, we present the Hierarchical Code-Recombination Autoencoder (HCRA), an architecture that achieves structural resilience for reconstructing plasma measurements, even in scenarios characterized by a massive lack of information, by decoupling individual diagnostic streams through a modular feature-extraction pipeline. Through a specialized recombination layer employing binary gating and learnable weights, the system autonomously reconfigures its focus based on signal availability. This hierarchical organization ensures flexibility, allowing sensors to be added or removed without fully redesigning the global neural topology.

The framework's robustness was validated through a methodological assessment within TokaLab environment, integrating synthetic Thomson Scattering, interferometry, polarimetry, and magnetic probes. By training on physically consistent synthetic observations, the model functions as a virtual sensor, reconstructing electron density and magnetic states even during total loss of primary local measurements.

Topological analysis of the latent space reveals the HCRA engages in a form of autonomous physical reasoning, by spontaneously disentangling the kinetic and magnetic manifolds. This guarantees inferences remain grounded in the governing physical laws, providing a robust, interpretable, and scalable framework for real-time plasma monitoring in next-generation fusion reactors.

Fast solution of heat diffusion equation on STRIKE calorimeter through Physics-Informed Neural Networks

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The STRIKE calorimeter is a diagnostic for characterizing the SPIDER negative ion beam, providing a spatially resolved map of thermal power deposition. Since front-side temperature measurements are not available on STRIKE, the incident heat flux must be reconstructed from rear-side infrared thermography data. Recent developments introduced a machine learning approach to reconstruct the front-side heat flux distribution directly from IR camera images, straight solving the inverse non-linear problem, mathematically ill-posed. To construct the training database, a FEM-based procedure was run iteratively to solve the direct problem. The convergence of the iterative procedure provided a target heat flux, which matches the experimental IR measurements on the back surface of STRIKE.

In this work, the use of Physics-Informed Neural Networks (PINNs) is explored to accelerate the solution of the direct heat diffusion problem. Starting with a single simulation of the FEM tile model, where the temperature from the STRIKE tile is extracted in 21 slices, the proposed approach trains a PINN. The inputs are the front surface heat flux, also used by the FEM, and the scalar value of the simulation time, while the output is the temperature field in the 21 slices of the tile at the given times. During the training, the PINN minimizes the residuals on temperature at the back, the heat diffusion PDE and the boundary conditions of the tile heat diffusion problem. By embedding the governing heat diffusion physics into the training process, the PINN learns to approximate the temperature evolution within the STRIKE tile with an error of 10%. The training of a PINN involves the convergence of multi-objective optimization, and this work explores the capabilities of the model to learn the evolution of one simulation, then the possibility of generalizing the model to learn a larger set of simulations will be investigated. The latter is the first step for the iterative use of the PINN to solve the direct problem in an iterative way, much faster than the FEM model. While the current FEM tile model requires approximately 30 minutes to solve a single direct problem, the trained PINN can deliver predictions in the order of seconds, obtaining a favorable speed-up when large databases need to be created. In addition, this system will be then integrated into the suite of beam analysis tools, allowing to compare the shape and position of the optimized front side heat flux distribution and the measured back side temperature.

IFMIF-DONES lithium target diagnostic based on mmWave radar (LiRADAR): system overview and first experimental results

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Topics

E. Diagnostics

Communication type

Oral

Abstract

IFMIF-DONES (International Fusion Materials Irradiation Facility – DEMOnstrator power plant Oriented Neutron Source) is an accelerator-based neutron source currently under construction in Granada (Spain). In this facility, a 5 MW deuteron beam impinges on a liquid lithium target flowing at 15 m/s and maintained at 300°C. The resulting deuteron-lithium stripping reactions produce a high neutron flux with an energy spectrum similar to that of future fusion reactors, thereby enabling testing of fusion-relevant materials.

A key component of this facility is the liquid lithium target, which must maintain a thickness of 25 ± 1 mm to safely absorb the beam energy and minimize the neutron flux losses. This region is subjected to intense radiation, high temperature, and lithium evaporation, making real-time diagnostics a challenge. To address this, a radar-based system operating in the millimeter-wave (mmWave) range has been proposed. This system is able to continuously monitor the lithium thickness and to detect flow instabilities, interfacing with the Machine Protection System (MPS) to enable rapid beam shutdown if the critical thickness is compromised.

The initial feasibility phase employed commercial radar kits operating in the similar frequency range foreseen for IFMIF-DONES and demonstrated proper precision and depth resolution through static and dynamic liquid target experiments. After the successful completion of these initial feasibility tests, the final radar-based diagnostic system, named LiRADAR, has been designed and fabricated. A 1:1 scale prototype of the IFMIF-DONES Target Vacuum Chamber (TVC), in which the radar antennas will be located, has been designed and manufactured to reproduce geometrical boundary conditions relevant to the target area, studying the LiRADAR behaviour and interferences under a realistic setup. The next experimental phase using the LiRADAR focuses on the measurements with static and dynamic liquid targets, as well as additional experiments with targets placed inside the TVC prototype

to assess resonance effects and spurious reflections induced by the complex chamber geometry.

This contribution presents an overview of the LiRADAR system and reports initial experimental results obtained in laboratory conditions representative of IFMIF-DONES. The outcomes provide key input for performance assessment, design validation, and further optimization of the final radar diagnostic for liquid lithium monitoring.

#12940

Overview of ITER neutron diagnostic calibration strategy

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Neutron emission and fusion power measurements contribute to achieving ITER mission by enabling the machine Q value estimation. ITER Tokamak is equipped with a set of Neutron Diagnostics systems to perform these measurements, in particular the Neutron Activation System, the Divertor Neutron Flux Monitors and the Neutron Flux Monitor. These diagnostics quantify activation in specific materials and count neutrons interactions in many in-vessel position, allowing in turn the assessment of the total neutrons emitted by the plasma.

The detectors response will be studied in isolation in laboratory environment, but this will not be sufficient to accurately assess their response once integrated in ITER Tokamak. This is due to the strong influence on the detectors' response of neutron interactions in the materials surrounding them and their environment.

To assess the machine influence on neutron diagnostics response, neutron calibration campaigns are needed. During these campaigns a set of detectors are irradiated with well characterized neutron sources able to produce neutrons similar to the ones produced by the plasma during operation.

At ITER, in situ calibration campaigns will be performed using DD and DT neutron generators in the phase in between the end of Assembly and the start of Integrated Commissioning, when the in-vessel environment will be the same as during Operation.

One calibration campaign will be performed before the start of each ITER operational phase to take into account the changes in detectors response due to the introduction of new components in the machine.

Extensive neutronic analyses have been performed to study neutron detectors responses, their sensitivity to different parameters and to plan and optimize irradiation campaigns.

A comprehensive calibration strategy has been defined including calibration campaigns objectives, detailed irradiation plans and response function determination methods.

The expected measurement uncertainties have been estimated and are demonstrated to be compliant with ITER requirements.

#12942

First tomographic reconstruction of the SPIDER multi-beamlet configuration

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The ITER neutral beam injectors (NBIs) must satisfy stringent requirements in terms of beam performance, in order to deliver 33 MW of power to the ITER plasma. Among the various beam properties, the optimisation of beam uniformity plays a crucial role. To investigate this aspect, a tomographic diagnostic has been installed in SPIDER, the ITER negative ion source prototype hosted at Consorzio RFX, to provide a comprehensive characterisation of the beam.

The system consists of 15 2D visible cameras, installed all around the vacuum vessel, which measure the light emitted in the visible range by the beam particles interacting with the background gas.

In this work, the uniformity of the SPIDER beam is studied and investigated through a 2D tomographic reconstruction of the beam emissivity pattern.

The Simultaneous Algebraic Reconstruction Technique (SART), based on the pixel method, is used as the inversion algorithm.

The reconstructed emissivity is then converted to beam current density, through a dedicated model to interpret the beam emission light. These estimates are correlated with the electrical measurements and with measurements performed using the STRIKE calorimeter.

The inversion technique has already been validated for characterising the optics of a limited number of open beamlets (28 out of the total 1280) during the initial SPIDER experimental campaigns, and it is now being applied for the first time to evaluate its performance in the multi-beamlet configuration, where up to 312 beamlets are extracted simultaneously. In this work, the algorithm is tested and optimised to assess the spatial resolution which can be achieved in this configuration, also tackling the challenges related to real world data analysis.

The results represent a key step in view of the application of visible tomography to the injector prototype MITICA at full energy and for long pulses.

Combining multiple synthetic diagnostics to construct a beam scenario database for ITER's Neutral Beam Injector prototype

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Neutral Beam Injectors (NBIs) are key technologies for future fusion reactors such as ITER, requiring high stability, uniformity, and precise control of high-power neutral beams (up to 46 A beam current at energy 1MeV in Hydrogen, coming from a precursor negative ion beam). To achieve the demanding requirements, a full-scale NBI prototype, MITICA, is hosted at the Neutral Beam Test Facility (NBTF), in Padua. The machine poses major engineering challenges due to the beam size and high power multi-beamlet structure thus, to evaluate the beam properties, MITICA will exploit a suite of heterogeneous diagnostic systems, providing a rich and complex dataset of measurements of different beam quantities.

To achieve a more complete understanding of beam features, an integrated framework combining data analysis, physics-based and machine learning modelling is under development. The first key step is to construct synthetic signals of a subset of diagnostics, building a database of beam scenarios, which shall be used at a later stage for training a machine learning model suitable for data mining.

In this contribution, the methodology for creating the aforementioned database is presented. Dedicated physics-based models are developed for different diagnostic classes, including thermo-mechanical sensors, calorimetry, and tomography. The modelling chain combines beam extraction and acceleration simulations, developed mainly via IBSimu, with beam propagation, power deposition, and diagnostic response calculations, relying on several tools, such as a custom ray-tracing code that computes power hitting 3D surfaces, a MATLAB-based implementation of the SART algorithm for tomographic reconstruction, and finite-element modelling with ANSYS. Nominal and off-nominal beam scenarios, including optics perturbations and misalignments, are simulated to populate the database. This activity represents the first step toward machine learning applications aimed at beam scenario classification and data interpretation, with the goal of providing engineering improvements for optimizing the first phases of MITICA operation.

#12955

Infra-Red Video Bolometer (IRVB) of Korea Superconducting Tokamak Advanced Research (KSTAR)

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Plasma radiation serves as a fundamental observable for characterizing power balance [1], boundary physics [2], impurity transport [3], and disruption dynamics [4]. The Infrared Video Bolometer (IRVB) offers a foil-based bolometric solution, where radiation absorbed by a thin platinum foil is imaged through a single pinhole aperture by an infrared (IR) camera positioned on the air side. This configuration naturally rejects electromagnetic interference while maintaining a simpler architecture than conventional resistive bolometers.

With the growing need for active plasma control, there is an increasing demand for real-time diagnostic tools. The KSTAR IRVB has been operating as a real-time diagnostic system since the 2023 campaign, with tungsten plasma-facing components (PFCs) in its lower divertor. The IRVB has been upgraded with improved system stability, streaming speed and profile data size, reconstruction algorithms, and increased automation. Since the 2026 campaign, the IRVB has been evolving into an agentic plasma diagnostic system integrated with a large language model (LLM), representing a step toward fully autonomous plasma diagnostics. The primary objectives of this agentic IRVB are interactive reconstruction tuning, self-correction through integration with other diagnostic data, and autonomous operation, ultimately enabling the diagnostic system to autonomously identify performance degradation, propose corrective actions, and guide users toward enhanced plasma diagnostics. Preparatory work has been conducted to develop each of these skills. The progress and details of these skills toward the agentic IRVB will be presented at SOFT 2026.

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Temperature Effects on Magnetic Measurements and Installation of hall Sensors in the KSTAR Tokamak

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Magnetic Diagnostic (MD) system in the KSTAR tokamak consists of magnetic sensors, analogue integrators, anti-aliasing filters, and digitizers. The magnetic sensors arranged in a poloidal array play a crucial role in plasma control. However, during long-pulse plasma discharges, magnetic sensors without sufficient thermal shielding exhibited significant increases in signal drift due to heating from plasma radiation.

To address this issue, thermal shielding structures were installed to protect the sensors from radiative heat loads. The effectiveness of the thermal shielding was clearly validated from the magnetic measurements after the magnetic sensors was covered with the shielding. In addition, Hall sensors capable of reliable operation in high-temperature environments were newly installed in the tokamak to enhance measurement stability under long-pulse conditions.

This work presents the characteristics of drift variation in magnetic sensor signals, the improvements achieved through thermal shielding, and the technical considerations associated with the installation of the new Hall sensors for long-pulse operation in KSTAR.

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Innovative radiometric calibration solution for optical diagnostics in fusion plants

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Radiometric calibration of optical diagnostic systems used in fusion reactors is crucial for monitoring and characterization of reactions in tokamak reactors.
These optical systems are composed of elements (i.e., mirrors, lenses, windows) located as close as possible to the fusion reaction in the vacuum chamber. They generally experience a degradation of their optical transmission over time due to environmental factors (radiation, dust, plasma sputtering, etc.). A shutter and a cleaning system can be implemented to mitigate these effects, but they cannot completely prevent transmission losses. Therefore, the system requires periodic recalibration to ensure the accuracy of the required measurements.
Given the extreme environmental conditions, the permanent installation of a calibrated light source in front of the system is impossible. The widely used solution is to place a retroreflector behind the shutter to perform calibration remotely. Various retroreflector-based solutions have been proposed, but they all rely on the long-term stability of the material's reflectivity. If it drifts over time (degradation), then the diagnostic measurements are biased (overestimation).
Numerous retroreflector designs have been proposed to address self-calibration, yet none achieves true absolute radiometric calibration independent of material degradation due to environmental conditions.
We present here an innovative solution that overcomes this limitation through a dual-shape retroreflector configuration.
It combines two types of mirrors with different effects. The first reflector returns light as an angle cube after three reflections, while the second induces a scattering effect with a single reflection. The difference in the number of reflections, combined with a different optical conjugation, allows for the measurement of the intrinsic reflectivity of the retroreflector material as well as the transmission of the optical system.
This concept has been successfully implemented in the Core Charge Exchange Recombination Spectroscopy (CXRS) diagnostic for ITER developed under F4E contract. Bertin Technologies experimentally demonstrated that the two signals can be separated and detected with a signal-to-noise ratio sufficient to achieve self-calibration of the reflector and, consequently, precise and absolute calibration of the optical transmission path.

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Investigation of thermal conductivities and contact conditions in UHV

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Topics

E. Diagnostics

Communication type

Poster

Abstract

A major goal of the W7-X stellarator is to achieve long-pulse operation up to 1800s at high plasma density. In order to ensure a safe operation of the diagnostics exposed to the plasma radiation cooling is inevitable. The two most common methods of cooling components in experiments are direct cooling, in which cooling water flows through channels in the components to be cooled, and indirect cooling, in which the components are mechanically connected to a cooling surface. Direct cooling of the component is preferable to indirect cooling, but it is more difficult to implement, especially with moving components.
This presentation focuses exclusively on indirect cooling and thermal contact conditions to optimize the heat transfer. A thermal contact is the intersection of two volumetric objects that allows heat to flow from the warmer body to the colder body. Since surfaces are never perfectly smooth, only a fraction of the actual contact surface contributes to the heat transfer. The remaining gaps act as thermal contact resistance, which limits heat transfer and causes a temperature rise at the interface. Thermal contact resistance depends on the type of contact, surface roughness, material, and contact pressure of the surfaces. To investigate thermal contact, two copper blocks are connected to a stainless steel pipe through which water flows. The connection is realized using three different methods. In the first method, two copper objects (100x100mm) are clamped onto the stainless steel pipe using a screw connection (4xM4). The maximum torque is used to achieve the greatest possible compressive force between the parts. The second method resembles the first one, but a graphite foil (Sigraflex) with 1mm thickness is added between the copper plates. In general, the graphite sheet increases the overall thermal resistance, but it also improves the surface contact thereby fostering heat transfer. For the third method, the connection between the cooling pipe and copper block is realized using an electroplated Copper layer (3mm thickness). For all methods the heat transfer is investigated in a UHV test chamber using the same conditions. A radiant heater (2000W) acts as a heat source. Thermal sensors monitor the temperature behavior until thermal equilibrium is achieved. The results are compared with the FEM (ANSYS) thermodynamic calculations.

Calorimetry in WEST: Global power balance and local in-situ measurement on the lower divertor

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Topics

E. Diagnostics

Communication type

Oral

Abstract

WEST is an actively cooled tokamak designed for long-pulse operation. Its cooling circuits are extensively instrumented ex situ, with 75 flowmeters and 101 PT100 temperature sensors, enabling calorimetry measurement of power loads and extracted energy on ten different components. When accounting for the various toroidal locations, this corresponds to a total of 94 monitored subcomponents. Missing data are extrapolated from measurements performed on similar components. After each plasma pulse, a global power balance is computed and is almost closed (around 85% of the injected power can be retrieved on all components). The remaining unaccounted power is mainly attributed to components that are not actively cooled and to uncertainties in water flow or temperature measurements. This paper presents the evolution of the WEST power balance from campaign C7 (2023), which was the first campaign with a fully actively cooled tungsten monoblock lower divertor, to campaign C12 (2025). The power balance is analysed for several lower single-null (LSN) configurations, such as an attached high-fluence scenario during C7 and a X-Point Radiator (XPR) high-fluence scenario during C12, but also for double-null and upper single-null configurations. The lower divertor is one of the most heavily loaded components in LSN configuration, receiving about 25% of the injected energy. Calorimetric measurements are able to capture the difference in the radiated power pattern after XPR transition, during which enhanced radiation leads to a reduction of the power deposited on the lower divertor and a corresponding increase on other components.

The discrete arrangement of toroidal field coils in WEST induces a strong ripple in the toroidal magnetic field, generating a heat-flux pattern on the lower divertor that repeats every 20°. The ex-situ calorimetry system cannot catch this localized heating, as each instrumented cooling loop covers 30° sectors of the lower divertor. To investigate ripple-induced modulation, an in-situ calorimetry system was therefore installed on selected pairs of tungsten monoblock plasma-facing components, spanning regions from maximum to minimum heat flux. To minimize the risk of water leaks inside the vessel, temperature measurements are performed using thermowells welded onto the cooling pipes. Pattern of the power deposition from campaign C13 (2026) will be presented and we expect that the power received by components at the maximum heat-flux location is approximately twice that measured at the minimum. The influence of plasma current and X-point height on the ripple modulation amplitude will be also discussed.

#12978

Remote Alignment Control System for ITER's CXRS Diagnostic: The Line-of-Sight Finder Approach

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Core Charge Exchange Recombination Spectroscopy (CXRS) diagnostic is a critical active beam spectroscopy system for ITER. The system measures ion temperature, toroidal rotation velocity, and impurity densities through spectral analysis of charge-exchange emissions from the Diagnostic Neutral Beam (DNB). The diagnostic features a complex optical transport system with five in-vessel mirrors (M1-M5) and three ex-vessel optical assemblies (Long Focal Telescope, Cold Dog Leg, and Optical Bench Assembly) that collect and inject light into a fiber bundle.

Maintaining optical alignment throughout ITER's operational life presents a formidable challenge. Multiple factors threaten the line-of-sight (LoS) stability: thermal expansion of the vacuum vessel from ambient to 100°C operation temperature, plasma disruptions, seismic events, radiation-induced structural degradation, and intense thermal cycling of in-vessel mirrors. Critically, access to the Port Cell and Interspace regions is severely restricted after initial installation, precluding conventional hands-on realignment procedures.

To address this challenge, a Line-of-Sight Finder capability has been integrated from the early design phase as an essential subsystem within the Optical Bench Assembly (OBA). The LoS Finder employs a side optical path that illuminates and images fiducial markers positioned at the intermediate focal and pupil planes within the Upper Port Plug without impacting the CXRS measurement performances. Radiation-hardened cameras capture these fiducial, which are then compared against calibration references to compute required alignment corrections.

The system enables remote verification and correction through three motorized assemblies (Cold Dog Leg, Optical Bench Assembly and the fiber bundle). This architecture provides both diagnostic (measurement) and corrective (actuation) capabilities without requiring physical access to the restricted radiation zone areas, representing a significant advantage over alignment strategies employed in other ITER diagnostics.

The poster will detail the optical design implementation, alignment tolerancing analysis and performances, and the comprehensive methodology for both initial commissioning alignment and continuous operational monitoring of the CXRS diagnostic.

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Monitoring of glow discharge boronization with quartz microbalance sensors at ASDEX Upgrade

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Topics

E. Diagnostics

Communication type

Poster

Abstract

With ITER’s decision to replace the beryllium (Be) wall by a full tungsten (W) first wall, glow discharge boronization (GDB) has recently become an important topic. To ensure good homogeneity of the GDB, multiple glow anode and gas inlet positions are required, which is incompatible with the already completed design of the wall conditioning system foreseen for the Be primary wall. Extensive simulations have been carried out to determine the optimal number and positions of the glow anodes and gas inlets for ITER's future GDB system, and the model has been applied to the ASDEX Upgrade (AUG) configuration. Therefore, experimental data from AUG are required to validate this simulation results. Time-resolved measurements at several locations are essential in order to assess the homogeneity of the coating.

To enable in-situ measurement of the boron (B) layer deposition during GDB, seven quartz microbalance sensors (QMB) are installed at various poloidal and toroidal positions. These sensors enable measurement of the layer thickness and its spatial distribution resulting from the GDB coating process. In addition, the accumulated layer erosion during plasma discharges over a single operation day can be determined. The QMB sensors extend an existing set of diagnostics at AUG, which previously did not allow direct measurement of the GDB coating: approximately 50 long-term witness samples are installed directly in the vacuum vessel, which enables ex-situ ion beam analysis and reflects the cumulative state after a complete campaign. Manipulator-based witness samples can acquire data from a GDB with limited spatial resolution. Furthermore, spectroscopic measurements of B/W radiation during plasma discharge provide information about the quality of the previous GDB coating.

A first setup of this diagnostic was installed during AUG maintenance in 2023/2024 and generated data during the 2024/2025 experimental campaign. Twelve GDB’s were performed during this period. The number of active glow anodes and the amount of working gas used were varied to investigate the effects of the coating. Scientific results have already been presented at several conferences, such as PFMC and PSI. In this article, we discuss the technical challenges of integrating these highly sensitive QMB measurements and their data acquisition systems into the harsh environment of a tokamak.

#13040

Performance Evaluation of ITER VUV Spectrometer Data Acquisition System with a Multi-Detector Configuration

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The ITER vacuum ultraviolet (VUV) spectrometers use CCD-based detectors to provide spectroscopic measurements for plasma diagnostics. Due to the inherent exposure and readout times of CCD detectors, a measurable latency exists between photon detection and data availability at the host system. This latency is an important performance parameter for ITER VUV spectrometers, particularly in relation to high-speed measurement requirements with minimal latency variation and potential interaction with plasma control. This poster presents an experimental performance evaluation of a data acquisition system developed for an ITER VUV spectrometer, with a focus on latency characteristics under high-speed operation. The system is designed to support a multi-detector configuration and to reflect representative ITER operating conditions, including centralized timing and long-distance signal transmission. Experimental tests were performed under representative data acquisition scenarios relevant to ITER VUV operation. The results show stable and repeatable latency behavior on the order of the acquisition cycle time, with limited frame-to-frame variation during extended measurements. The impact of different acquisition scenarios on latency characteristics is also examined to assess their applicability to multi-detector operation. These results demonstrate that the proposed data acquisition system satisfies key performance expectations for ITER VUV spectrometers and supports further system integration and extension.

Bolometric reconstructions and characterisation of radiation losses in highly emitting regions of DTE3 plasmas

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Topics

E. Diagnostics

Communication type

Poster

Abstract

One of the main experiments of the most recent DT campaigns of JET, i.e DTE2 and DTE3, has been the development of a stable, high-current baseline scenario [1]. Impurities, primarily beryllium (Be) and tungsten (W), affected baseline plasmas and accumulated predominantly on the low field side region of the device. At the same time, bolometric reconstructions (tomograms) revealed the formation of localized regions of intense radiation in the proximity of the plasma edge. The presence of these peripheral radiative zones played an important role in limiting the penetration of impurities towards the plasma core, which could result in performance degradation or even trigger premature discharge termination, i.e. disruption[2]. The mechanism was effective when a stationary Edge Localized Mode (ELM) regime was sustained, which helped to maintain impurity screening throughout the discharge [1]. The present contribution is thus devoted to the analysis of bolometric tomograms of a selected set of DTE3 baseline discharges in order to retrieve the radiated power and the radiation density profiles associated with these strongly emitting regions. Tomograms have been reconstructed using a maximum likelihood approach on JET that has been developed and tested over the past few years [3]. The preliminary results indicate that the non-uniformly distributed radiation peaks relatively close to the top of the pedestal. Furthermore, it has been estimated that they account for approximately 78% of the radiation losses from the core region and around 71% of the total radiation. The results of this analysis are expected to provide valuable insights to disruption mitigation studies and modelling activities. Further efforts are also currently planned to extend the analysis to a larger baseline database.

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#13058

GPU-accelerated IR image processing for real-time temperature mapping and hotspot tracking in the UWAVS diagnostic (ITER)

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Upper port Visible/IR Wide Angle Viewing System (UWAVS) requires fast and reliable extraction of surface temperature and hotspot features from infrared (IR) image streams for machine protection and plasma control applications. We developed a C++/CUDA software prototype to assess the feasibility to achieve hot spots detection and tracking targeting sub-10 ms latency per 1920×1536 frame. The pipeline includes GPU kernels for (i) median filtering to mitigate impulsive detector artifacts, (ii) LUT-based conversion from digital levels to surface temperature (mono-color), (iii) local adaptive thresholding for candidate hotspot segmentation, and (iv) an original GPU Connected Component Labeling (CCL) scheme.

The proposed CCL partitions the binary mask into overlapping tiles labeled in parallel, followed by multi-pass border fusion and label-equivalence resolution. A GPU-based connected-component list extraction further reduces device-to-host transfers and accelerates blob feature computation. Hotspot characterization and temporal tracking (size filtering, spatial merging, persistence) are executed on CPU over the reduced component list.

Performance was assessed offline on pre-recorded IR image sequences (e.g. JET/KL7) resized to ITER-relevant image sizes. Performance assessment on an RTX TITAN platform shows average end-to-end processing of ~2.5–2.6 ms/frame including transfers, and stable operation over 1-hour continuous runs. By overlapping the temperature-map transfer with other process of the pipeline using asynchronous CUDA streams, most of this transfer can be hidden; the effective end-to-end latency drops to ~1.6 ms/frame on the same platform. While the CCL fusion step can exhibit non-deterministic labeling under specific synthetic patterns due to concurrent updates of label equivalences, downstream blob merging mitigates most impacts; atomic-based fusion is identified as a key improvement path. These results demonstrate the feasibility of low-latency IR thermal imaging and hotspot tracking for fusion diagnostics under realistic image sizes.

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#13092

Implementation of novel magnetic field sensors on COMPASS-U, DTT, and DEMO/VNS tokamaks

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Reliable magnetic reconstruction in future fusion reactors demands diagnostic systems capable of withstanding extreme operational environments while delivering the high-fidelity signals required for advanced plasma control. This contribution details the engineering design and integration of novel magnetic sensors for COMPASS-U, DTT, and DEMO/VNS.

The paper is focused on the combined magnetic sensor for COMPASS-U. Standard inductive sensors suffer from integration drift, while commercial semiconductor Hall sensors fail under high neutron fluence and elevated temperature. To resolve this, we present a robust hybrid design combining Thick Printed Copper (TPC) coils with radiation-hardened Antimony based Hall sensors within a unified, space-efficient housing.

The TPC coils provide exceptional reliability and bandwidth, while the collocated Hall sensors enable steady-state measurement.

We detail the engineering required to install these sensors into the limited volume of the COMPASS-U Low-Field Side (LFS) outer wall limiter. Finite Element Analysis (FEA) validates the design against substantial electromagnetic and thermal stresses, ensuring the sensors do not compromise the limiter's structural integrity. Parallelly, for the DTT facility, we address the spatial integration of Antimony based Hall sensors into the DTT vacuum vessel. By validating sensors on near-term devices, this work establishes a proven hardware platform scalable to the harsh environments of future fusion reactors.

#13098

In-Vessel Viewing and Metrology System for ITER: Validation Testing on Full-Scale Divertor and on damaged Plasma Facing Components

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The In-Vessel Viewing and Metrology System (IVVS) is a diagnostic tool for the ITER project, designed to inspect plasma-facing surfaces within the tokamak. Following the construction and validation of a full-scale prototype of the measurement probe compatible with the final harsh environment in 2023, recent progress has showcased its application on a full-scale divertor inner-vertical target (IVT) and on real, damaged tungsten Plasma Facing Unit (PFU) from CEA WEST that had been exposed to plasma. The plasma-exposed WEST target showed various surface changes, currently being studied, and could have major implications for the ITER project or any tungsten-based tokamak.

The tests done by Bertin Technologies have successfully validated the performance of the IVVS at ITER-relevant viewing angles, distances, and focal parameters, over ITER-specific geometries, and at full cable/fiber length, confirming its suitability for in-vessel use. They have also shown the capabilities of the system to detect deposition on the WEST tungsten due to plasma environment interaction with real tiles.

On the IVT measurement campaign, the system clearly detected geometrical features such as tile gaps and edges, with the metrology channel providing precise range measurements with precision on planar areas of 0.1 mm from 0.5-10m and angles from 0-60 degrees. Over the full IVT geometry, dimensional errors are

Preliminary Design of the High Resolution Neutron Spectrometer for ITER

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Topics

E. Diagnostics

Communication type

Oral

Abstract

As part of a comprehensive set of neutron diagnostics, ITER's High Resolution Neutron Spectrometer (HRNS) will integrate both novel and well-established neutron energy measurement techniques into a single diagnostic system. Its primary measurement role is to determine the tritium-to-deuterium ion fueling ratio (nt/nd) with better than 20% uncertainty in the plasma core (r/a < 0.3). This measurement will contribute to fusion plasma control in real time. HRNS also serves as backup diagnostic for the core-plasma ion temperature, and provides complementary information to determine the fast ions energy distributions.

This paper reports the overall engineering status achieved during the recent Preliminary Design phase, and describes the four integrated spectrometers: Thin-foil Proton Recoil (TPR), Diamond Neutron Detector (NDD), back-scatter Time-of-Flight (bToF) and forward-scatter Time-of-Flight (fToF). These spectrometers share a single neutron beam emitted from the plasma through the Equatorial Port Plug, the Radial Neutron Camera ex-vessel structure and the Bioshield wall. The beam is collimated by the Radial Gamma Ray Spectrometer system which is positioned just in front of HRNS. The spectrometers work in different, overlapping

ranges of fusion power to maximize the ITER operational space covered by HRNS.

Within the HRNS installation, in the Equatorial Port Cell #01, the four spectrometers intercept the incoming neutrons sequentially. Their operation is supported by key subsystem components: nuclear sources and picosecond laser for detector characterisation and time synchronisation; detector magnetic shielding; a local air thermal-conditioning system based on chilled water; a shielded cabinet for pre-amplifiers; thermal and magnetic-field monitoring; and integrated shielding walls to mitigate scattered neutrons into the port cell. The design approach adopted for these elements, results in a performant, robust and reliable diagnostic system.

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Commissioning of STUMM-PROTO at UGR-DONES: Prototype Implementation and Lessons Learned for the Future STUMM System

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The commissioning of STUMM-PROTO at the UGR-DONES facility represents a significant milestone in the development of the neutron and gamma characterization strategy for IFMIF-DONES. STUMM-PROTO is a full-scale (1:1) prototype of the future STUMM (Start-Up Monitoring Module) system, conceived as an experimental platform to validate design solutions, detector integration strategies, and signal acquisition design under representative boundary conditions.

The prototype has been designed and manufactured to support an experimental programme aimed at characterizing detector behavior under controlled and configurable conditions. One of its primary objectives is to assess detector response under varying thermal boundary conditions simulating neutron heating. In addition, STUMM-PROTO enables the study of detector performance in configurations involving high detector density within a constrained envelope, allowing investigation of cross-talk, mechanical constraints, and integration challenges.

A dedicated focus of the experimental campaign concerns signal integrity over long transmission distances. The system incorporates a 35-meter transmission line, reproducing the distance between the Test Cell and the acquisition room, to evaluate attenuation, electromagnetic susceptibility, and robustness of the acquisition system. This configuration is particularly relevant for micro-fission chambers (MFC), micro-ionization chambers (MIC), and Self-Powered Neutron Detectors (SPND). The integration of fast electronics operating as a trigger allows simulation of sudden beam deviation events, enabling validation of response times and reliability under transient conditions representative of beam perturbations.

From a mechanical standpoint, the STUMM-PROTO vessel has been designed and manufactured in accordance with RCC-MRx

standards for nuclear components. Fabrication included qualified welding procedures, material traceability, non-destructive test procedures, dimensional control, and overpressure testing to verify structural integrity and leak tightness.

This work presents the key lessons learned during commissioning across thermal, mechanical, and electronic domains. Thermal tests confirmed the need for controlled heat distribution and boundary conditions to ensure representative detectors behavior. Mechanically, assembly activities highlighted the importance of proper detector integration, reliable connections, and valve and sensor integration. From the electronic perspective, the acquisition and control system architecture proved essential to ensuring reliable data acquisition performance. A robust control implementation ensured stable prototype operation, while grounding, shielding, and signal conditioning preserved signal integrity over long transmission distances. In addition, the high adaptability of STUMM-PROTO enables replication of different detector configurations and operating scenarios, reinforcing its role as a powerful test bench for qualification of the final STUMM system.

These outcomes provide direct input for the final STUMM design, contributing to risk mitigation, improved integration planning, and enhanced operational reliability within IFMIF-DONES.

Divertor Tokamak Test facility diagnostic systems integration and design: current status and future perspectives

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The Divertor Tokamak Test (DTT), an experimental facility under construction at the ENEA Research Center in Frascati, Italy, has been designed to address power exhaust challenges under integrated, reactor-relevant conditions similar to those expected in ITER and DEMO.
In the last years DTT diagnostic activities have progressed significantly. New strategies, coherent with DTT Research Plan and construction schedule, have been put in place to finalise the design and to set up the framework for the procurement and the delivery of the diagnostic systems planned for the commissioning and early experimental operation. Moreover, a major effort has been made to address integration challenges also for the diagnostics required in the subsequent phases, to ensure that the equipment will be completed when the machine will reach full power. In parallel, a thorough assessment of the diagnostics' integration aspects in terms of requirements formulation, front-end definition, interfaces identification, and space allocation within and outside the Torus Hall has been performed.
This body of work, developed in the framework of the machine assembly specification activity, constitutes the most comprehensive information so far for the completion of the technical specifications for the installation of the diagnostic systems.
This paper will provide an overview of DTT diagnostics advancement status, focusing mainly on integration issues and future challenges.

#13138

Vision Based Real-Time Monitoring and Deep Learning Enhanced Droplet Detection for Ceramic Breeder Pebble Production

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Topics

E. Diagnostics

Communication type

Poster

Abstract

At the Karlsruhe Institute of Technology (KIT), lithium-rich ceramic pebbles are manufactured using the KALOS (KArlsruhe Lithium OrthoSilicate) process. These pebbles will be featured in so called breeding blankets in the wall of future fusion reactors and generate the tritium required to fuel the reaction. Monitoring the controlled breakup of the laminar molten jet by adjusting the excitation frequency is essential for production, as it is at this stage that the size distribution of the pebbles is predominantly determined. A controlled pebble size is critical for the packing factor and therefore performance of the breeder blanket.

In this contribution, we present the complete system that has been developed for this purpose, consisting of a high-speed camera and an image-processing pipeline. A central element is the reliable segmentation of the molten droplets, performed with a deep neural network (DNN) that has been trained on learning data recorded under real-process conditions. From the segmentation results, important information such as the droplet geometry or the distances between successive droplets can be extracted. The normalized standard deviation of the droplet distances, i.e. the coefficient of variation (CV), provides a quantitative assessment of the regularity of the molten jet breakup. Small CV values, hence a regular jet, indicate a more periodic breakup and consequently more uniform pebbles after solidification. Beyond process monitoring, regulating the CV value by adjusting the excitation frequency allows the production of pebbles with a low size tolerance. A control-strategy based on this concept is also presented in this work.

The operation of the vision-based real-time monitoring system is demonstrated through several experimental series in which the excitation frequency is varied. A comprehensive characterization of the pebbles generated in these experiments, such as measuring their size distribution, provides a direct benchmark for validating the monitoring system outputs.

In summary, this contribution presents the design, operation, and performance of the high-speed camera based monitoring system that supports the optimal production of lithium-rich ceramic pebbles for future fusion reactors.

#13147

Final sensor design, layout and validation of the ITER diagnostic pressure gauges

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The ITER diagnostic pressure gauges are designed to measure the neutral gas density in the boundary layer of the ITER plasma at several locations: at the low field side mid-plane in two equatorial port plugs, at six generic positions on four divertor cassettes, and in ducts in four lower ports. As this diagnostic will close its Final Design Review mid-2026, and specifications are being prepared for its procurement, this presentation will review the chosen sensor design, the layout of the diagnostic, and all validation tests performed to verify that the sensors, integration of crucial components, and electronics achieve environmental and measurement requirements for ITER.

The sensor is a modified hot ionisation gauge suitable for operation in high magnetic fields in the environment of a fusion device and demanding operational lifetime. The concept is based on the ASDEX pressure gauge but uses an indirectly heated ZrC block as electron emitter. The emitter successfully passed tests demonstrating its reliable emission in relevant gas environments like H2, D2, He, Ne, and Ar at heating currents below 9 A. The emitter support was developed to sustain typical mechanical forces (e.g. accelerations due to disruptions) and repetitive thermal cycles for switching the sensors on and off. The sensor was calibrated in various gas environments and various magnetic fields up to 8 T for pressures up to 20 Pa. It was also proven to withstand exceptional pressure increases up to 230 Pa due to disruption mitigation measures, and a lifetime of 860 h in 20 Pa H2 atmosphere at steady state conditions could be verified.

For the operation of the sensor, new dedicated electronics were developed to provide potentials and heating current for feedback-controlled electron emission, as well as to measure the resulting ion current down to the nA range with heating current supervision and sensor temperature measurement. The main feature of the electronics, its capability to perform reliable and noise-reduced measurements in combination with up to 200 m long cables as needed for ITER, was verified successfully.

Furthermore, the reliability of the electrical connection of the sensor using mineral insulated cables was verified by thermal tests on prototypes, demonstrating the maximum temperature they can sustain during thermal cycles. Also, welding trials demonstrated the achievability of tolerances needed for the installation on divertor cassettes and in lower port ducts.

#13153

High-Resolution, Multi-Channel Spectroscopic Diagnostics of the ASDEX Upgrade Neutral Beam Injection System

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Topics

E. Diagnostics

Communication type

Oral

Abstract

A new spectroscopic system for the neutral beam injection (NBI) of the ASDEX Upgrade (AUG) tokamak extends the applications of this diagnostic far beyond the well-established Doppler-shifted Hα beam emission spectroscopy used to determine beam divergence and beam species composition [1].
The upgraded setup uses an HRS-750 spectrometer connected to a ProEMCCD1024 camera and a 20-channel fiber array, providing simultaneous measurements from multiple lines of sight (LoSs). These LoSs observe plasma emission from 8 gas neutralizers spread across 2 injector boxes and 4 RF plasma sources in injector 2, with high spectral resolution (~20 pm) and a time resolution of ~5 ms.
Characterization of the plasma inside the gas neutralizers is important for predictive modelling of the neutralization efficiency and for the accurate calculation of the three energy fractions of the injected neutral beam from the Doppler-shifted Hα spectra as well as for benchmarking existing neutralizer plasma generation models. The high spectral resolution allows us to measure the temperature of H atoms from thermal Doppler broadening (~ 1000 K) while the molecular gas temperatures can be derived from measurements of the Fulcher-α band (D2 or H2). Spectral line ratios of the Balmer line series (for D or H) enable the determination of electron temperature and density through collisional-radiative modeling [2].
The neutral beams are often modulated to achieve heating power ramps via pulse-width modulation at a ~ 50 Hz repetition rate. The improved time resolution now allows us to observe changes in beam parameters during the short individual blips, leading to a nonlinear dependence of the average power on the modulation duty cycle. Accurate characterization of these effects is essential for discharge analysis, particularly to provide accurate input for transport modelling.
Simultaneous spectroscopic diagnostics of multiple LoSs facilitate the identification of correlations among beam parameters, neutralizer plasma, and the plasma of the RF sources in injector 2. These results should inform the current models of gas neutralizers and improve the power calculations required for NBI operation in the ASDEX tokamak.
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#13180

Preliminary electromagnetic design of the Doppler Reflectometry system for the JT-60 tokamak

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Topics

E. Diagnostics

Communication type

Oral

Abstract

This work describes the preliminary electromagnetic design of the Doppler reflectometry system to be installed in the JT-60SA tokamak in the framework of the EU-Japan Broader Approach agreement to fusion power, with the objective of demonstrating high-performance plasma scenarios and the validation of integrated control and machine protection systems for long-pulse operation.

Continuing the initial efforts on the feasibility studies of a Doppler reflectometry system in JT-60SA [1], conceptual design was further explored under the assumption of a change in the access port and a realistic space reservation. Hence, both injection angle ranges and frequency ranges were evaluated using ray tracing for the two possible modes of propagation and different scenarios in order to maximize the density fluctuation wavenumbers that can be explored. This led to baseline conditions in terms of frequency and density that can be used as an starting point for a design, around which expected variations were acceptable.
From the determination of the cut-off layer and its radius of curvature for this baseline conditions, the optimum waist in this layer can be calculated, which is the input for the design of the quasioptical system. Additionally, due to the large bandwidth involved, frequency invariance of the system is desirable, leading to a Gaussian telescope arrangement. Unfortunately, the source antenna is not invariant itself, which means that an odd number of quasioptical elements must be used with the objective of equalizing the variation imposed by the emitting source.

Finally, preliminary loss calculations were performed for the different waveguide technologies, taking into consideration several placements for the source and detection equipment, with the objective of providing a feasible waveguiding path.

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Design and performance of the ITER Collective Thomson Scattering (CTS) ex vessel quasi-optical interface components

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The ITER Collective Thomson Scattering (CTS) is a diagnostic aimed at measuring the dynamics of alpha particles in the plasma. The CTS is a complex diagnostic spread throughout several ITER buildings, with signals being transmitted across long transmission lines. Furthermore, the CTS front-end is located in a remote handling port-plug, meaning that the interface between the ex-vessel and in-vessel subsystems of the CTS must be quasi optical. Also, the CTS launcher line, transmits a 1MW gyrotron beam whilst the receiver transmission lines are carrying very low power signals.
With the aforementioned design limitations, it becomes essential for the transmission lines to be low loss since, on the side of the launcher, losses result in high heat loads, and, on the receiver side, signal losses result in low signal to noise ratio.
Matching Optics Units (MOUs) are complex components with, at-least, two reflectors whose surfaces are responsible for receiving a gaussian beam from a source and coupling it to a target. As such, signal losses will be a function of both the shape and material of the mirror surfaces. Furthermore, losses will increase with misalignments between the signal source, the reflectors and the target, misshapen mirrors, and with lower-than expected material conductivity. These later effects are a result of material and manufacturing quality and, thus, are stochastic in nature, albeit controllable. In this work we perform a Monte-Carlo analysis on the launcher and receiver MOUs of the CTS whilst introducing several different geometrical deviations and material variability to assess how the losses (ohmic, distortion, cross-polarization and coupling) are affected.
From our results, we assess the statistics for the MOUs' losses and use them to guide their design and manufacturing.

#13201

Tritium-tomography via MeV ion-beam analysis

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The Tritium (T) chemical similarity to the abundant hydrogen isotopes and its 18.6 keV 3-body decay make it difficult to detect. Nuclear fusion requires an analysis method, which allows detecting absolute amounts of T separated from other radioactive emitters, the other hydrogen isotopes, in small quantities, non-destructive, and spatially-resolved. Several options exist, but with distinct limitations. Extending the analysis capabilities would add valuable information for the T inventory and its distribution in a fusion. In particular, a tomographic information adds valuable information e.g. on T-retention and plasma-surface interaction understanding.

MeV Ion Beam Analysis (IBA) can provide these analysis qualities, but the T detection, in particular in W, remains difficult. In this work we investigate 100 kBq/cm^2 and 180 MBq/cm^2 T in 2 µm W layers made in Romania by IBA. We optimize the analysis setup regarding projectile energy (~1 MeV), projectile species (deuterons) and detection geometry by designing an IBA scenario providing the maximum possible detection range of 2.2 µm in W, considering pile-up and the overlap of the D-T reaction with backscattering in a typical IBA setup. We obtain a detection limit in the order of 100 ppm (≈ 1019 T/m^2) for imaging and 1 ppm for single point analysis with longer integration time.

We compare this optimized deuteron IBA to other established T analytics. This comparison highlights the value of the presented IBA approach for analyzing fusion related samples, e.g. from T campaigns in JET or ITER. With this knowledge IBA can support the development of in-situ T-diagnostics such as laser induced ablation by providing absolute reference values.

The 1 MeV deuteron analysis is conducted in our µNRA setup, demonstrating the practical detection limit and the feasibility considering noise and the strong W pile-up signal, in particular in a tomographic analysis requiring high ion-beam currents. The measurement also investigates the literature cross-sections by comparing the IBA T inventory with the known sample activities.

Lastly, we assess nuclear safety by providing measurements using handheld dose-rate and contamination monitors. The results show a clear response of these devices, in spite of their specified lower detection threshold being significantly above the T-decay energy, an information of high practical utility for T operations. Using a Silicon Drift Detector (SDD) in our IBA setup we demonstrate the excitation of W-L X-ray lines at ~9 keV through the interaction with the particles emitted by the T decay, an effect known in literature as BIXS.

#13208

Rapid synthetic IR diagnostic for ITER first wall heat load control applications

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Monitoring of heat fluxes to the ITER tungsten first wall (FW) is essential for machine protection and plasma control. Such control is required from the start of plasma operation, both for the inertially cooled wall in place for the Start of Research Operation (SRO) and the later actively cooled wall for the DT phases. The First Wall Heat Load Control (FWHLC) function currently being developed within the ITER Plasma Control System (PCS) design activity will operate on real-time thermal load estimates derived from IR camera surface temperature measurements and plasma heat flux reconstructions on plasma-facing components. These measurements are provided by the ITER Equatorial Wide-Angle Viewing System (EWAVS). However, the interpretation of IR data for control design is not straightforward. This paper describes the development of a synthetic IR diagnostic workflow for EWAVS with particular emphasis on the generation of fast and reliable synthetic signals and images, with defined requirements for their use in the PCS FWHLC design.

The InfraRed Imaging Synthetic Diagnostic (IRISD) presented here allows fast simulation of entire plasma SRO scenarios, modeling the plasma conductive heat loads and wall thermal dynamics, together with the camera characteristics and limitations, to generate the synthetic images and signals expected to be sent to the PCS. The IRISD platform is being developed for full compatibility with the IMAS (Integrated Modelling & Analysis Suite) framework. The architecture emphasizes fast yet reliable PCS signal generation, realistic sensor effects, and well-defined output interfaces tailored for FWHLC testing in open-loop coupling. To enable fast analysis, the workflow uses a set of modeling approximations which are compromise between higher-fidelity simulation realism and computational efficiency, aiming at achieving processing times down to minutes for an entire ITER scenario. Our studies concentrate on the calibration of a 1D FW thermal model against higher-fidelity finite volume simulations and examines reflection contributions in the workflow. Specifically, the impact of specular reflections is assessed using the deterministic ray-tracing code Speculos. The resulting errors in the measured surface temperature and the effects on thermal load estimates are thoroughly evaluated.

Our work also aims to support the definition of requirements for the data transmission between the EWAVS diagnostic and the PCS, where bandwidth limitations prevent the transmission of full IR images. To address this constraint, the two main measurement parameters simulated with IRISD are the maximum FW surface temperature on pre-defined regions-of-interest and the surface temperature provided as a 2D pixel subframe.

SAPPHIRE-SSD: a Sensor Advancement Project to Produce an Highly Innovative, Resilient and Economical Solid State Detector

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The rapid advancement of nuclear fusion technologies is driving the need for reliable and robust diagnostic systems capable of monitoring key plasma parameters for both control and research purposes. Among the available techniques, fast neutron counters and spectrometers have demonstrated the capability to assess fundamental quantities such as fusion power, fuel ion ratio, and plasma temperature.

Solid-state detectors (SSDs) represent a promising solution for fast neutron detection in fusion environments due to their compactness, mechanical robustness, radiation hardness, and relative insensitivity to gamma radiation. In particular, diamond detectors currently represent the state of the art of SSDs, having achieved significant results at JET. However, issues related to long-term stability, operational limits in harsh environments, and the complexity and cost of their production process leave room for further innovation in the SSD field.

This contribution presents the first research and characterization activities on a novel SSD concept based on sapphire (Al_2O_3), an economical, mechanically robust material with a well-established manufacturing technology in the optics industry. Sapphire features a very wide bandgap, which (although typically considered a limitation for conventional electronic devices) becomes advantageous in high-radiation and harsh environments, enabling stable operation and intrinsic discrimination against lower-energy radiation components.

The first sapphire detector prototypes have been manufactured and tested using laboratory calibration sources and fast neutron fields to evaluate their response, radiation hardness, and discrimination capabilities. Experimental results are presented to assess both the potential and limitations of this innovative diagnostic approach. A comparison with existing neutron detection technologies (like diamond or SiC detectors) and with numerical simulations is also discussed. Finally, future developments and planned experimental activities are outlined, with particular focus on the possible implementation of sapphire-based SSDs in next-generation fusion devices.

Design status of the ITER Collective Thomson Scattering ex-vessel launcher transmission line

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The ITER Collective Thomson Scattering (CTS) diagnostic will measure parameters of the velocity distribution function of fast ions. It will be located at ITER´s equatorial port EP#12 and it will consist of two primary subsystems: a high power launcher Transmission Line (TL) and nine receiver TLs which route the signals through different plant areas. The launcher TL injects a high power microwave beam (1.2 MW @ 60 GHz) into the plasma. The scattered power along different angles will be guided by the receiver TLs to the microwave detectors.

The launcher TL consists of oversized circular corrugated waveguides (CCWG), miter bends, expansion units, a Matching Optics Unit, cooling channels, isolation/shutter valves, a DC break and a pump-out system. Oversized CCWG in vacuum conditions are used to minimize the power losses. The internal diameter is 88.9 mm and the materials are chosen based on safety and structural integrity analyses. Al6061-T6 is used for general segments, SS 316L(N) is used in critical sections where structural/safety criteria are more demanding, and CuCrZr alloy is used in sections where high heat loads are expected.

A significant challenge in the design is the management of the different safety classifications (SIC-1, SIC-2, and non-SIC) and the structural and space constrains. In addition, the design of the launcher TL must fulfil the microwave performance requirements, i.e. maximum transmission efficiency with low power and low mode conversion losses. To optimize the transmission efficiency, the launcher TL uses a self-alignment design through high-precision male-female flange connections which ensure high concentricity between adjacent TL components. In addition, the design tolerances ensure that tilting at the connecting interfaces between any two components of the TL is low enough to reduce the mode conversion losses.

In this work, a general overview of the ongoing design for the ex-vessel launcher TL will be presented.

Keywords: ITER, Collective Thomson Scattering, CTS, Microwave Transmission Lines, Microwaves, Waveguides.

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Neutron Camera Response Prediction with CADIS in OpenMC

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Scintillator-based neutron cameras have been used or proposed for use in a wide variety of fusion experiments, from the Joint European Torus and the Large Helical Device to the International Thermonuclear Experimental Reactor and the SPARC tokamak. A well-calibrated and characterized neutron camera can provide spatially-, temporally-, and energy-resolved information about the neutron emission rate within a fusion plasma. These measurements are closely related not only to total fusion power and gain, but also to quantities like ion temperature and density. However, simulated as well as in-situ calibration procedures can be costly and time-consuming processes due to the detectors' low geometric efficiency, and the difficulty of modeling the system to a high degree of fidelity often results in high uncertainty. To facilitate higher-fidelity simulations of a neutron camera, this work describes the development of new weight windowing and source biasing capabilities using the Consistent Adjoint-Driven Importance Sampling (CADIS) technique within OpenMC. These techniques are then applied to a model of a neutron camera and a tokamak with a realistic neutron source. The CADIS method considered in this study leverages the capabilities of the random ray solver in OpenMC to calculate adjoint flux maps for adjoint sources corresponding to detector responses of interest, thereby enabling the automatic generation of weight windows and source biasing parameters for local variance reduction. In contrast to contemporary CADIS workflows, this is done without the need to interpolate between meshes or transfer between geometric representations--a unique capability among state-of-the-art Monte Carlo transport codes. Additionally, unlike standard approaches where adjoint data is first calculated using a deterministic discrete ordinates code, the use of the random ray solver also provides a continuous angular treatment, counteracting ray effects in problems where flux anisotropy is ubiquitous. In this work, the simultaneous reduction of variance in multiple discrete responses is demonstrated, and the feasibility is discussed of extending these methods to assist in the calibration of a heterogeneous neutron diagnostic set.

#13250

Optical design of a top-port injected laser focusinf lens for the KSTAR divertor Thomson scattering system

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Topics

E. Diagnostics

Communication type

Poster

Abstract

A divertor Thomson scattering (DTS) system is currently under design and implementation for the Korea Superconducting Tokamak Advanced Research (KSTAR), building on the development experience of a tangential TS system in KSTAR.
However, DTS signals are expected to be extremely weak (Te: 1 - 100 eV, ne: 1x1018 - 1x1019 m-3), and their analysis will be challenging due to the stray light inside the KSTAR vacuum vessel. To minimize stray light entering the collection optics, the configuration of the laser beam path and the laser beam dump plays a critical role.
Following the preliminary design of the DTS system, the collection optics system was designed, and the laser beam dump was fabricated and installed to ensure compatibility with the KSTAR divertor module.
In this study, the laser focusing lens for the DTS is designed under the assumption that the laser beam is injected through the top-port of the KSTAR tokamak. The laser beam propagates a distance of approximately 6.3 meters within the KSTAR tokamak, focusing at the divertor X-point region before entering the laser beam dump located in the divertor module.
This paper presents the design of the laser focusing lens for DTS and discusses the simulation results in detail. The results confirm that the proposed design enables the laser beam to be injected through the top-port and successfully captured by the laser beam dump at the bottom-port of the KSTAR tokamak. These results will provide a crucial technical foundation for the future optimization of the DTS laser focusing system of KSTAR.

Development of a modular vacuum-ultraviolet spectrometer for JT-60SA

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Vacuum-ultraviolet (VUV) spectroscopy is one of the key diagnostics in magnetically confined fusion plasmas, enabling investigation of impurity transport and monitoring for safety operation. In this study, we report the development of a VUV spectrometer system for JT-60SA designed to observe impurity line emissions from a core plasma.

Two flat-field, grazing-incidence spectrometer modules are prepared. One spectrometer, Survey module, covers a wavelength range of 0.5-50 nm with a holographic grating having 300 grooves/mm, providing a wide spectral coverage to monitor line emissions from impurity ions. The other spectrometer, High-Resolution module, covers a wavelength range of 0.5-5 nm with a holographic grating having 1200 grooves/mm. It achieves a spectral resolution of 2 pm full width half maximum at 5 nm, enabling the resolution of closely spaced lines in the extreme ultraviolet range. In each module, the dispersed light is focused onto a flat focal plane with a width of 30 mm and detected by a dedicated CCD camera with an imaging array of 2048 x 2048 pixels and an active area of 30.7 mm x 30.7 mm, capturing the full wavelength range without mechanical scanning of the CCD camera.

Each module, with a size of 150 mm in width, 670mm in length, and 50mm in height, is mounted in a dedicated vacuum chamber connected to a JT-60SA horizontal port. Each module integrates the entrance slit, holographic grating, and detector within the casing. Thus, the modules can be exchanged without disturbing the optical alignment. This feature enables future upgrades, such as replacing the grating to extend the wavelength coverage, while minimizing commissioning time.

The VUV spectrometer system is being developed for the next experimental campaign, which is planned to begin in 2026. Prior to the installation to JT-60SA, each module will be wavelength-calibrated using VUV light source to obtain the pixel-to-wavelength corresponding.

#13263

Development of a finite element method based equilibrium reconstruction model for transient and off-normal plasma phases in KSTAR

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Topics

E. Diagnostics

Communication type

Poster

Abstract

In this study, a Finite Element Method (FEM)-based equilibrium analysis code was developed for the KSTAR tokamak to characterize plasma behavior during highly transient and off-normal phases, including early startup, pre-disruption, and Vertical Displacement Events (VDEs). During these stages, conventional EFIT reconstructions often fail to achieve numerical convergence due to rapid topological changes and extreme plasma configurations. The developed code utilizes magnetic diagnostic data [1] - including flux loops, magnetic probes, and Rogowski coils - and explicitly incorporates external coil currents and conducting structures susceptible to induced eddy currents. The validity of the FEM model was first established by comparing its results with EFIT for stable plasma discharges. Subsequently, equilibrium reconstructions during VDE stages were presented and cross-validated with other diagnostic measurements. These results provide deeper insights into the VDE dynamics accompanying KSTAR disruptions, establishing a vital computational foundation for managing electromagnetic risks and ensuring the structural integrity of future fusion reactors.

#13288

Development and testing of amorphous platinum front end mirror coatings for optical fusion diagnostics

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Lifetime assessments of platinum- and rhodium-coated first mirrors (FM) used in fusion diagnostics suggest that coating thicknesses on the order of several micrometers may be necessary to withstand erosion due to plasma cleaning cycles and due to particle fluxes bombardment, while preserving optical performance. It is suggested that platinum coated mirrors may have enhanced performance in comparison with rhodium ones due to improved thermal stability and reduced susceptibility to oxidation and corrosion in high radiation/temperature environments. The uniform structure of amorphous coating enhances thermal stability and adhesion, reduces thermal stress and the risk of delamination. In this work, amorphous platinum films produced by ion beam assisted deposition are investigated as candidate technology for such applications. The fabrication of micrometer-scale coatings presents significant challenges, including the accumulation of residual stress and thickness-dependent variations in microstructure and mass density, both of which can influence optical performance. Fabrication of prototype first mirrors is reported with coating thicknesses of 0.2, 1.6, 5 μm and 10 μm deposited on ITER grade stainless steel substrates followed by tests in various plasma conditions. These samples were exposed to 40.68 MHz radiofrequency discharge in dedicated test facilities, with ion fluxes in the range of (1–9) × 10^{19} ions·m^{-2}·s^{-1} and cumulative ion fluences up to 2 × 10^{24} ions·m^{-2} in helium and hydrogen plasmas. Such ion fluxes were used (i) to reproduce plasma cleaning lifetime effects and (ii) to mimic erosion with charge exchange atomic fluxes. Typical ion energy distributions had peak energies centered around 115 eV for helium and 250 eV for hydrogen. This was consistent with earlier investigations of FM coatings and plasma cleaning optimization strategies. Surface composition and morphological evolution were characterized using X-ray photoelectron spectroscopy and scanning electron microscopy. Scanning electron microscopy revealed that platinum coatings with thicknesses of 5 and 10 μm appeared rougher in topology than those with a thickness of 1.6 μm. Under the investigated helium and hydrogen ion fluxes, the specular optical reflectivity of the FM prototypes remained largely unchanged. The results further indicate that blistering may constitute the dominant erosion mechanism, particularly in the presence of residual water vapor, in agreement with observations reported in previous studies.

Electromagnetic loads and resulted stresses on the Optical Box under ITER Divertor Dome designed for the Erosion Deposition Diagnostic System

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Optical Box, installed beneath the Divertor Dome as part of the Erosion Deposition Monitor diagnostic system, distributes laser light and optical signals between the divertor targets and the camera system. Due to its location inside the tokamak, it is exposed to significant electromagnetic loads during plasma transients such as disruptions and vertical displacement events.

This study builds on the Preliminary Design Review (PDR) configuration and aims to further optimize the Optical Box from an electromagnetic and structural perspective. The work systematically investigates how geometric modifications (e.g., wall thickness, segmentation, stiffening elements and current paths) and material variations influence induced current densities and the resulting electromagnetic forces.

Time-varying toroidal and poloidal magnetic fields are considered as sources of induced currents. From the computed current density and magnetic flux density distributions, volumetric Lorentz forces are derived and transferred to structural analyses to evaluate the resulting stresses.

A detailed finite element model of the Optical Box is integrated into a global tokamak electromagnetic model to ensure realistic boundary conditions. By comparing the baseline PDR design with optimized variants, the study identifies the key design parameters governing electromagnetic forces and structural response, supporting further design refinement and improved robustness under severe plasma-induced loads.

Extraordinary Claims Require Extraordinary Measurements: A Diamond-Based Telescope Detector for Nuclear Fusion Neutron Diagnostics

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Diamond-based neutron detectors are essential for both private and public nuclear fusion facilities, providing reliable measurements of neutron flux and energy distributions in harsh environments. Consequently, these systems will be a primary diagnostic tool for verifying any breakthrough $Q > 1$ energy gain claims. Due to the neutron interaction mechanism, the measured spectrum does not correspond to the neutron energy spectrum. Combined with high gamma-ray background and scattered neutrons, extracting meaningful data often requires computationally intensive deconvolutions.

To circumvent these limitations, a four-stage diamond telescope detector was adapted to directly measure the neutron energy distribution down to 2 MeV, via recoil protons. Complex post-processing is eliminated, through real-time coincidence measurements. The telescope detector can concurrently detect fusion neutrons from 2.45 MeV Deuterium-Deuterium (DD) and 14.1 MeV Deuterium-Tritium (DT). In this work, first results from a measurement campaign at the EC-JRC MONNET facility are presented, including data collected at fusion-relevant DD and DT energies. These results are compared to simultaneous direct neutron measurements for both monoenergetic fields and mixed neutron environments relevant to nuclear fusion.

#13305

The Infrared Thermography System for First Wall Protection in WEST

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The WEST tokamak is equipped with a comprehensive infrared (IR) thermography system dedicated to first wall monitoring for both machine protection and physics studies. Designed to support long-pulse operation, it provides real-time surface temperature measurements of plasma-facing components and detailed post-pulse thermal analysis of steady-state and transient events.

This paper presents an overview of the IR thermography system (both the hardware and software ecosystem) and illustrates how classical and AI-based approaches jointly enhance machine protection, diagnostic reliability, and physics exploitation.

The machine protection system relies on 11 in-house IR-cameras (operating at 50Hz with 640×512 pixels) installed on five actively cooled endoscopes located in upper ports, covering approximately 80% of the lower divertor and all heating systems, complemented by a wide-angle tangential view observing about one-sixth of the vessel. Two additional diagnostics support physics investigations: a very-high-resolution (VHR) system with 100µm pixel resolution for divertor mono-blocks studies, and a fast IR-camera (FIRCA) observing the divertor with millimetric spatial resolution and a sampling rate up to 3kHz.

The software framework combines real-time protection with post-pulse analysis tools. Real-time processing coupled to the plasma control system includes temperature thresholding in predefined regions of interest for injected power regulation, and two CNN-based detectors (custom convolutional neural network) dedicated to electric arcs on lower hybrid antenna grills and to runaway electrons. In parallel, a GPU-based Thermal Event Detection model performs real time detection, tracking, and classification of heat load events. Post-pulse tools include automated detection of flying particles (“UFOs”) and a synthetic “shot summary” providing operators with an overview of all views immediately after each discharge.

From 2023 to 2025 (campaigns C7–C12), about 23 hours of cumulated plasma duration were performed, with an overall IR thermography system availability of 96% on plasma pulses with auxiliary heating. As WEST progressively explored more demanding plasma scenarios, injected power regulation from the IR system became increasingly required, rising from 13.3% of the pulses in C7 to 36.4% in C12, thereby enabling safe operation while maintaining high plasma performance.

Despite their robustness, these methods measure apparent temperatures and remain sensitive to thermal scene evolutions. To address

these limitations, an IR digital twin (called IMPACT) is being developed to improve machine protection without restricting the operating domain, a key requirement for high-performance long-pulse operation.

Modelling neutron emission for the ITER High-Resolution Neutron Spectrometer

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Neutron emission provides valuable information about a fusion plasma. In ITER, the High-Resolution Neutron Spectrometer (HRNS) will determine the fuel-ion ratio and ion temperature, which are key parameters for understanding plasma performance. The HRNS must have a time-resolution of 100 ms and operate across fusion power levels ranging from 0.5 MW to 500 MW. To meet these requirements, the diagnostic must be precisely designed based on the expected neutron emission in various scenarios.

We developed a modelling scheme for predicting spatially and spectroscopically resolved neutron sources from various fusion reactions in magnetically confined fusion plasmas. Supported reactions include thermal and beam-thermal deuterium-tritium fusion. The ASCOT orbit-following code is used to calculate the slowing-down distributions of fast ions, such as beam ions. The DRESS spectrum-simulation code is used to calculate the spatially resolved neutron spectra based on reactant distributions. The geometry of a diagnostic sightline, for example that of the HRNS, can be taken into account to calculate the spectrally resolved neutron flux into a diagnostic. To validate the modelling scheme for reactor-relevant plasmas, predictions are compared to neutron measurements in JET.

A sufficient fraction of beam-thermal neutrons compared to the total neutron emission is crucial for determining the fuel-ion ratio [1]. In the ITER baseline scenario, with Q = 10, we predict the fraction of neutrons from beam-thermal fusion to be around 3%, but this fraction varies between scenarios. We calculated the neutron spectrum seen by the HRNS for a range of ITER scenarios, with variations in several plasma parameters, such as temperature, density and fuel-ion ratio. These results have been used in a detailed performance evaluation for the HRNS [2].

[1] M. Scholz et al 2019 Nucl. Fusion 59 065001
[2] L. Hägg et al 2026 submitted to the 34th Symposium on Fusion Technology

#13326

Progress in the Design of Bolometry and Soft X-Ray Diagnostics for COMPASS-Upgrade

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Topics

E. Diagnostics

Communication type

Oral

Abstract

COMPASS-U is a high-field tokamak under construction at IPP Prague, featuring tungsten plasma-facing components and a hot wall operation intended to gradually reach 500°C. It is designed to support ITER-relevant studies and to address key challenges in the design and development of the DEMO reactor.

COMPASS-U will be equipped with a bolometer and soft X-ray (SXR) diagnostic systems. The bolometry system comprises metallic foil bolometers that provide absolutely calibrated measurements of radiated power, and AXUV diodes for monitoring fast events. Foil bolometers achieve a time resolution on the order of 5 ms, in contrast to the ~1 μs resolution of AXUV diodes. SXR and AXUV diagnostics utilize photodiode arrays. Two sets of SXR cameras with different beryllium filters are intended for the study of impurity transport and MHD phenomena. All three diagnostic systems will be installed in the same segment of the vacuum vessel (1/16th) and share significant engineering challenges, mainly limited by operational temperatures requiring active cooling.

Three poloidal locations have been selected for these systems: the midplane port plug, near the bottom divertor, and above the top divertor. These positions ensure sufficient observation angles for expected studies and the computation of tomographic inversions; however, placement near the hot first wall is required to achieve the necessary fields of view. This poses a challenging engineering task due to the limited space available for thermal insulation and cooling systems.

The midplane port plug is approaching its final design review and should be available for the beginning of operation. Thermal analysis indicates that passive cooling, a shutter mechanism and installation at a sufficient distance from thermally critical zones are adequate to prevent detector damage in the event of an active cooling failure during operation at temperatures up to 500 °C.

The cameras near the divertors are currently in the conceptual design stage, with the goal of withstanding temperatures up to 300 °C and serving as a testbed for higher-temperature operation. The final positioning of the detectors near the upper divertor will be determined once the design of the plasma-facing components (PFCs) is finalized.

Kapton-insulated cables qualified for in-vessel use, with a maximum allowable operating temperature of 250 °C, have been selected and will be routed in parallel with the cooling pipes.

Optimization of ITER In Vessel Neutron Diagnostic Calibration

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Topics

E. Diagnostics

Communication type

Oral

Abstract

ITER requires accurate determination of neutron yield, with maximum uncertainties of 20% for DD and 10% for DT plasmas. Meeting these targets requires in-vessel neutron diagnostic calibration campaigns prior to DD and DT operational phases, using a remote-handling arm to deploy a portable neutron generator. These campaigns establish the calibration coefficients of the neutron diagnostics and ensure absolute measurements of physical parameters during operation. However, exhaustive experimental calibration over the full torus is impractical in ITER, due to the machine size, extensive shielding, limited neutron-generator strength, and the dynamic range and sensitivity of the neutron diagnostics, and time constraints. This necessitates an optimized strategy to realize the best possible accuracy within these constraints.

To address these limitations, a numerical framework was developed to optimize the in-vessel calibration procedures. The approach consists in reconstructing the Green's function from an optimal set of calibration points. These matrices correspond to spatial maps of the detector response to neutron point source throughout the plasma volume. This approach enables a reduction of the experimental scan and the optimization of source-deployment locations.

This numerical framework was used to assess the achievable calibration performance and the accuracy of neutron diagnostics with respect to ITER's operational objectives.

#13355

Antimony Hall sensors with enhanced performance for fusion power reactors

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Hall sensors have been proposed as a part of the DEMO magnetic diagnostics to perform absolute measurements of the steady-state magnetic field. They will contribute to measurements of the plasma current, plasma-wall clearance and local perturbations of the magnetic flux surfaces near the wall.
This contribution presents enhanced Hall sensors based on an antimony nanolayer. Key improvements include reducing the thickness of the sensitive layer to tens of nanometres, enhancing sensitive layer stability with a W-Ti adhesive interlayer, incorporating W-Ti diffusion barrier bridges, and increasing the sensor supply current. These sensors can operate continuously at temperatures of up to 400 °C and short-term at temperatures of up to 500 °C. The combination of a thinner sensitive layer and a higher supply current significantly increases sensors sensitivity. The test results of the sensors are presented.

Estimation of Uncertainty in the Line-of-Sight of the ITER In-Port Radial Neutron Camera due to Fission Chamber Isotopic Composition

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The purpose of the radial neutron camera (RNC) at ITER is to determine the plasma neutron emission profile from measurements of collimated neutron detectors. In this paper, a simplified CSG model for the OpenMC code is presented which was developed for sensitivity analysis of ITER neutron diagnostics. This model was modified by adding an equatorial port and integrating a simplified model of the in-port RNC which was developed based on the C-Model with the in-port RNC. The number of cells was reduced by approximately 3 orders of magnitude while retaining main features like gaps which were expected to significantly contribute to the signal of the RNC detectors. This model was used to determine the ratio between the number of neutrons emitted from the nominal line-of-sight (LOS) to number of neutrons emitted from the rest of the plasma as a function of the enrichment of U-238 inside the fission chambers. This was done by utilizing the CellBornFilter of OpenMC on additional void cells inside the plasma region, which represent the nominal LOS while the MAGIC method was used for weight window generation. Additionally, a 640-group neutron flux energy spectrum was calculated at the detectors which was used to estimate the uncertainty in the detector signal due to the uncertainty in the fission cross section of U-235 and U-238.

Final design of the ITER Tokamak Systems Monitor

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The ITER Tokamak relies on extensive engineering instrumentation to monitor its thermal, hydraulic, structural, and electromagnetic behaviour. The Tokamak Systems Monitor (TSM) combines the sensor data with advanced numerical algorithms to determine the machine performance during operation, address the health status, determine any wear and tear measurable effects, and assess the operating envelope. Emphasis has been placed on the detailed characterisation of plasma termination events, including disruptions and vertical displacement events (VDEs), as well as the thorough evaluation of their impacts from early operation phases.
In its final design, TSM provides near real time assessment of the systems integrity, evaluation of operational margins and component lifetime, and detection of anomalies across a wide range of tokamak systems. Reconstruction capabilities span thermo hydraulic, thermomechanical, structural static and dynamic, and electromagnetic domains, calculating relevant engineering parameters such as applied forces and reactions, geometrical configurations, heat fluxes and flows, peak temperatures, maximum stress, or accumulated fatigue. A dedicated anomaly detection module integrates machine learning based algorithms, including intershot classification and online, time localized detectors, to identify unexpected behaviours and support early intervention. A dedicated database is used for managing early warnings raised by the anomaly and limits detection algorithms, so that they can be confirmed or dismissed by the operator as part of the monitoring process.
TSM is built as a modular framework with hundreds of individual algorithm instances managed by an orchestrator, in coordination with ITER Supervisory System. Each monitoring instance is run within an Application Manager to easily read and write up to thousands of variables on CODAC Networks. To manage its execution and evaluate the outputs, TSM features two complementary

Human–Machine Interfaces: an operational interface for configuring and executing monitoring algorithms during pulses, and a data analysis interface for detailed intra and post pulse interpretation, model calibration and data fusion with other diagnostics.
This paper presents the final design of TSM's reconstruction, health status, and anomaly detection capabilities, detailing their development, validation workflow, and integration within ITER's operational environment.

Transitioning Compact Bolometer Cameras from passive to active cooling with 3D-printed casings through the Wendelstein 7-X Project

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Topics

E. Diagnostics

Communication type

Poster

Abstract

After the successfully completed Operations Phase (OP) 2.1 (Date: 22/09 - 23/03), where the actively cooled divertor was used for the first time,
Wendelstein 7-X has taken a significant step towards continuous operation. With an 8-minute long discharge, W7-X reached a new peak value. Existing diagnostics must now be reviewed and possibly improved using finite elements method (FEM) to meet the specified requirements, including active cooling enhancements or design modifications.
In case of the Compact Bolometer Camera (CBC), which was installed for OP 2.2 (24/09), the cooling concept relied on passive cooling with the already installed port liners. To operate three CBCs in standard diagnostic mode for 100 seconds with a 1GJ energy limit, as well as during continuous operation, the concept had to be switched to active cooling.

A major focus of the design was to realize active cooling within the housing and exclude ECRH radiation from the diagnostics. This was achieved through 3D metal printing. The opening (pinhole) in the plasma chamber within the printed casing is uncloseable, but the detector heads containing the measurement chips are shielded with a metal wire mesh so that microwaves cannot enter. The design also focused on channel layout of the cooling circuits. Limited temperature stability requirements for 3D printed parts and minimizing changes to the existing housing geometry influenced the design. These arguments were decisive in choosing 3D printing over conventional manufacturing methods. With help from flexible tubes and extensions to the execution flange with an additional daughter flange, end-assembly of the cooling system became possible.

The installation of the three actively cooled CBCs during OP 2.4 (planned start date: 26/09) was successful, and the cooling is connected to the main cooling circuit. Further optimization needs to be addressed regarding the exact alignment of detector heads when assembling diagnostics. To simplify assembly, additional design modifications for electrical

connections would also be necessary.

#13512

Combined sensor for COMPASS-U - validation of data fusion aspects

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The design of a new local magnetic field sensor was recently finished at the Institute of Plasma Physics of the Czech Academy of Sciences and University of West Bohemia. The set of 4 of these sensors are to be mounted in an outer wall limiter of COMPASS-U tokamak. The sensor utilises two orthogonally arranged printed coils based on the Thick Printed Copper (TPC) technology together with two correspondingly arranged Hall sensors with antimony sensing layer on TPC base with W-Ti diffusion barrier. Both sensing components demonstrated resistance against high temperature and high neutron fluence. The sensor housing is manufactured from Inconel using 3D printing technology.
This contribution presents analysis of response of the combined sensor to outer magnetic field in broad frequency range from DC to 100 kHz. The performance of the Kalman filter applied on coil-Hall pairs in baseline filter version is analysed. Potential of deployment of such novel combined magnetic field sensor on next devices accompanied by application of advanced data fusion algorithms is discussed.

Design of the Remotely Replaceable ITER First Wall Samples Diagnostic for Erosion and Fuel Retention measurements

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Topics

E. Diagnostics

Communication type

Oral

Abstract

This article presents the design of the ITER First Wall (FW) sample, a compact and remotely replaceable diagnostic system developed to quantify FW erosion by energetic charge-exchange neutrals (CXNs) as well as hydrogen isotope (H/D/T) retention at the FW surface. Approximately 126 FW sample (FWS) units will be installed in shallow recesses (< 22 mm) relative to the FW leading-edge at selected poloidal and toroidal locations, enabling spatial mapping of net erosion/redeposition and fuel retention across the FW surface. ITER will be the first fusion device to deploy such a large and high-resolution distributed array of replaceable FWS, providing broad poloidal and toroidal coverage for in-vessel diagnosis of plasma–wall interactions. Here, we describe the overall FWS architecture as well as the detailed engineering designs of the two dedicated sample adapters. This design incorporates a specialized structural concept engineered to withstand the extreme thermal gradients and mechanical loads expected under ITER-relevant high-heat-flux conditions. Based on the thermal and structural analyses of the FWS and adapters, this research demonstrates their compliance with unique ITER design criteria and confirms adequate performance margins. The FWS and its adaptor ensure both mechanical integrity and repeatable positioning while enabling full compatibility with the ITER remote-handling (RH) system for installation and removal. Moreover, the development and qualification of a bespoke remote-handling (RH) tool for FW samples, the RH bolt runner, designed to sustain repeatable installation and removal under ITER's strict remote-maintenance requirements and challenges, will be presented. Design characteristics, operational constraints, and the interface design with the ITER RH system are described in detail.

Instrumented high fluence neutron irradiation test of antimony Hall sensors

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Hall sensors with metallic sensitive layers exhibit significant resistance to elevated temperatures and high fluences of ionizing radiation. They have been qualified for operation in the radiation environment of ITER and are being installed as Outer-Vessel Steady State magnetic-field sensors of the device. They are also being considered for deployment in the European demonstration fusion power plant (EU-DEMO), where the expected neutron fluence is one to two orders of magnitude higher than that anticipated for ITER. While extensive research is underway to evaluate the long-term high-temperature stability of metallic Hall sensors at EU-DEMO–relevant temperatures, no experimental data is available regarding the sensors' radiation hardness in EU-DEMO–relevant irradiation conditions.

To extend the qualification to the more demanding EU-DEMO radiation environment, an instrumented high-fluence neutron irradiation experiment was conducted in which antimony Hall sensors were exposed to neutron and gamma radiation in the core of the LVR-15 research reactor. Over the course of 4 irradiation campaigns the sensors were exposed to high energy ($E \geq 100$ keV) neutron fluence of 3.6×10^{20} cm^{-2}. After the accumulated fluence, they show no significant or abrupt radiation induced damage to their sensitivity and sensing capabilities. These results indicate that metallic Hall sensors are suitable candidates for deployment in EU-DEMO. This contribution describes the irradiation experiment and presents the principal findings.

ITER Outer Vessel Steady-State (OVSS) magnetic field diagnostic system: current status, R&D and production highlights, and lessons learned

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Magnetic confinement fusion reactors must ultimately operate in a steady-state regime to make thermonuclear fusion a commercially viable energy source. One of the key challenges along this path is that the accuracy of inductive magnetic field sensors for measuring slow evolutions of magnetic field is compromised in long plasma pulses and over extended measurement cycles. This occurs primarily due to DC (or quasi-DC) noise voltages generated within the measurement chain—induced by radiation and temperature effects—which are indistinguishable from the signal generated by changes in magnetic induction, while both are integrated by the data acquisition system. The solution to this problem is the incorporation of true steady-state magnetic field sensors within the magnetic diagnostics to directly (non-inductively) measure the local magnetic field in real time.

The ITER tokamak is piloting this approach by instrumenting three Vacuum Vessel sectors with a total of 72 units (24 per sector) of specially developed, radiation-hard metal-based Hall-effect magnetic sensors. Each of such unit integrates two Hall probes to simultaneously measure the tangential and normal components of the magnetic field, respectively. The design, development, qualification, production, calibration, and installation of this diagnostic system has been a decade-long joint endeavour of multiple participating members.

This proposed contribution will summarize the current status of this diagnostic system, major R&D and production highlights, and the lessons learned throughout this multiannual and highly multidisciplinary project.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Optical fiber-based monitoring of neutron transport in concrete within the EUROfusion concrete shielding experiment at the Frascati Neutron Generator

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Topics

E. Diagnostics

Communication type

Oral

Abstract

In the context of the EUROfusion Work Package Breeding Blanket (WP-BB), an experiment with optical fiber sensors was carried out at the Frascati Neutron Generator (FNG) facility of ENEA in Frascati, Italy.
The objective of this irradiation campaign was to investigate the transport of the 14 MeV neutrons generated at FNG through several concrete slabs. This was done by comparing the results of Monte Carlo codes with the response of different detector technologies: activation foils, silicon carbide detectors, lithium-glass GS20-type detectors, and also a set of silica-based radioluminescent optical fibers, to investigate the potential of this technology for neutron monitoring.
Optical fiber dosimeters present several advantages compared to electronic solutions (size, weight, EMI and temperature resistance, etc.), another one for radiation-rich environment is their capability to deport the most sensitive electronic components used to probe the radiation sensitive fibers to radiation-free zones, up to tens of meters away.
The doping of the cores of such fibers with specific scintillating elements (Ce3+ ions, in this case) enables a phenomenon known as radiation-induced luminescence (RIL), in which the charges released by the radiation recombine radiatively at Ce-related recombination centers resulting in a luminous signal that, for the best optical fibers, is proportional to the dose rate to which the fiber is exposed.
Their efficiency to monitor 14 MeV neutrons flux was proven at FNG during multiple previous campaigns, which showed that the RIL signal faithfully follows the reference neutron counters of the facility in the studied neutron ranges (10^5 ÷ 5×10^8 n cm^-2 s^-1)).
In this work, three 1 m long samples of Ce-doped optical fibers (two samples made with different techniques and the last one co-doped with Gd) were used to investigate the neutron flux attenuation through concrete inside the mock-up placed in front of the FNG target. This mock-up is composed of 13 slabs (each 5cm thick), and the fibers were moved across 7 different positions, with a measurement every two slabs.
The results confirm that the selected fibers are capable of measuring the real time neutron flux in all the investigated positions, with a total flux (obtained through MCNP5) varying between 2×10^5 and 2×10^7 n cm^-2 s^-1. To conclude the investigation, the attenuated spectra were simulated in MCNP5, and then convoluted with the dose over fluence characteristic of the chosen optical fibers to obtain the dose rate in silica corresponding to the flux in each position.

TOKIRA: an Automated Infrared Image Alignment for In-Vessel Component Mapping in the WEST Tokamak

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Topics

E. Diagnostics

Communication type

Poster

Abstract

In fusion devices, infrared cameras monitor the inner vessel to detect and track hot spots on Plasma-Facing Components (PFCs). However, automated analysis is challenging due to camera shifts caused by mechanical vibrations of the machine, displacements caused by maintenance, or movement of in-vessel components such as heating antennas. While human experts can manually identify PFCs, real-time applications (like power feedback control) require dynamic and reliable mapping between image pixels and components.

We introduce TOKIRA (TOKamak InfraRed Alignment), a method to estimate the geometric alignment between infrared images using a deep-learning model. This approach focuses on PFC localization and identification within the IR image, while deliberately excluding thermal data analysis from its scope. Developed as a first demonstrator for the WEST tokamak's wide-angle infrared view, which resembles one of the tangential views of ITER's Wide-Angle Viewing System (WAVS), TOKIRA aligns new images with a reference image initially matched to a simulated vessel model. This alignment enables accurate identification of the PFC associated with each pixel.

Given a reference infrared image and an infrared movie, for each frame, the method consists of three steps:
• Geometric alignment of the non-moving in-vessel components using a global spatial transform;
• Geometric alignment of the ion-cyclotron resonance heating antenna using a localized spatial transform;
• Detection of the reciprocating Langmuir probe when visible.

Tested on a large dataset of WEST infrared images, TOKIRA achieves pixel-level alignment accuracy for fixed PFCs and robustly isolates the motion of movable components like the antenna. While this work demonstrates an offline prototype, the approach supports real-time deployment, enabling stable pixel-to-component mapping across experimental campaigns without manual recalibration. This capability is essential for automated data analysis and machine protection in long-pulse devices like ITER.

An infrared video compression algorithm dedicated to high data volume analysis

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Long-pulse operation of fusion devices generates unprecedented volumes of infrared (IR) video data, making conventional offline analysis increasingly impractical. During the C11 and C12 experimental campaigns, the WEST tokamak accumulated nearly 10 hours of plasma operation, including the world record discharge of more than 22 minutes, producing IR data streams exceeding 400 MB/s for 12 lines of sight. This data volume represents a major bottleneck for large-scale thermal analysis of Plasma Facing Components (PFCs).

Current IR video analysis mainly relies on extracting temperature time traces within Regions of Interest (ROIs). However, standard video compression codecs such as H.264, currently used at WEST for IR videos, are not designed for scientific data exploitation: they require full-frame decompression even to access a single pixel time trace, resulting in prohibitive computation times and limiting systematic data mining.

We propose a dedicated infrared video compression algorithm explicitly designed for high-volume thermal data analysis. The method departs from conventional frame-based video codecs by directly encoding individual pixel temperature time traces, using temporal decimation combined with a bounded-error compression scheme. This guarantees a controlled temperature precision while enabling direct and random access to pixel or ROI time traces without full video reconstruction.

For typical IR analysis use cases, the proposed approach enables time-trace extraction speeds ranging from one to three orders of magnitude faster than the current H.264-based workflow used on WEST. Moreover, for temperature uncertainties above 2 °C, the algorithm achieves higher compression ratios while preserving superior image quality compared to current WEST compression algorithm at equivalent error levels, significantly improving long-term data archiving efficiency.

The algorithm has been applied to reprocess IR videos from the last 4 WEST campaigns, enabling the deployment of a dedicated data server optimized for on-demand time-trace extraction across arbitrary combinations of discharges, views, and ROIs. This infrastructure unlocks new large-scale analysis capabilities, including campaign-wide PFC monitoring, surface state evolution studies, and global thermal behavior analysis. The compression algorithm has been routinely used on WEST since the C12 campaign and is available as an open-source C++ library.

Opto-mechanical Design of the Optical Pellet Diagnostic Prototype for the ITER Disruption Mitigation System

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Shattered Pellet Injection (SPI) will be employed in the ITER Disruption Mitigation System (DMS) to reduce the impact of plasma disruptions by accelerating large cryogenic pellets and shattering them before they enter the plasma. This process produces a plume of smaller fragments that dissipates plasma energy. An Optical Pellet Diagnostic (OPD) subsystem is integrated into the ITER DMS to detect successful pellet launch and to provide real-time information on pellet integrity, size, velocity, and trajectory.
A concept OPD has been successfully designed, built, and tested with real pellets at the ITER DMS Support Laboratory SPI facility at the HUN-REN Centre for Energy Research, demonstrating the feasibility and functionality of such a complex diagnostic system. Based on these experiences, a prototype OPD has been developed to meet ITER requirements. These include operation within limited available space while maintaining accessibility for surrounding components, tolerance to the expected deformation of the injector system, and the use of materials compatible with neutron radiation and, in certain cases, ultra-high-vacuum conditions.
In this contribution, we present the developed prototype OPD setup, with particular emphasis on the implemented opto-mechanical design solutions.

Overview of ITER diagnostics and their contribution to ITER Research Plan

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Approximately 50 diagnostics and their services will be installed on ITER, distributed in 25 ports, on the vacuum vessel surface, and in the divertor. These diagnostics will measure more than 100 parameters necessary for the tokamak protection, plasma control and scientific exploitation. The design of most of the ITER diagnostics is now finalized, with many diagnostic components already manufactured, delivered, and installed. This year also marks the start of the assembly of diagnostic ports on the ITER site.
ITER diagnostics will be subject to new challenges unprecedented in today's tokamaks. The diagnostics will operate in a nuclear environment which requires the design to mitigate the transmutation, radiation damage, and thermo-electric effects, as well as to cope with nuclear heating. The diagnostics will be subject to very limited or no maintenance, and they need to be designed with very high reliability and/or redundancy. The diagnostic components installed inside the vacuum vessel require rugged design to withstand e.g. bakeout conditions and exposure to steam. Since ITER is a nuclear facility, the design, manufacture and installation of the diagnostic components is subject to stringent safety and quality requirements, in particular for components installed on or constituting nuclear confinement barriers such as the vacuum vessel feedthroughs and windows.
This contribution will show how these challenges are successfully met in the diagnostics' design through standardization, implementation of the quality requirements, dedicated R&D, and design for protection and replacement of critical items. The recent progress on the prototypes, manufacture, and installation of the ITER diagnostics will be summarized. The presentation will also address the contribution of individual diagnostics' measurements to ITER Research Plan – in particular the Start of Research Operation – and the associated planning of the diagnostics commissioning activities.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

TWINTOK-IDA: An integrated validation and benchmarking digital twin framework

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The maturation of a Digital Twin Environment (DTE) for magnetic confinement fusion necessitates a rigorous, automated framework to benchmark complex physical models against experimental observations. This work details the evolution of the TWINTOK digital twin platform [1], now synergistically coupled with the Integrated Data Analysis (IDA) framework. TWINTOK-IDA addresses the pivotal challenge of establishing a self-consistent reference state by integrating high-fidelity simulations with a robust Bayesian engine, thereby bridging the epistemological gap between sparse diagnostic data and deterministic physics models.

A defining attribute of the TWINTOK-IDA architecture is its inherent modularity, facilitating compatibility with diverse simulation suites. While SOLEDGE-HDG [2] serves as the primary driver for investigating heat exhaust and plasma evolution, the framework has demonstrated versatility through successful integration with other prominent codes, including SOLPS-ITER, JINTRAC, and GYSELA. This flexibility ensures that the validation pipeline remains independent of the specific transport or gyrokinetic model being evaluated.

The synthetic diagnostics (SDs) within the pipeline, including visible cameras, spectroscopy, bolometry (Raysect/Cherab [3,4]), interferometry (TIP), ECE, and reflectometry (FeDoT), are designed to be strictly machine-agnostic. By using the IMAS data standard [5], the SDs only require Machine Description (MD) Interface Data Structures (IDSs) to automatically set diagnostic specifications and detector positions. Furthermore, through the wall IDS input, TWINTOK-IDA can be easily adapted to any tokamak geometry, ensuring seamless portability across WEST, ASDEX Upgrade and TCV.

By systematically interrogating how perturbations in magnetic configuration, impurity concentration, and plasma density manifest in diagnostic signals, TWINTOK-IDA minimizes epistemic uncertainties within the validation cycle. This project marks a strategic transition from a proof-of-concept prototype toward a validated, user-oriented service, providing a "living model" for real-time decision support and predictive operation. Such an integrated, modular paradigm significantly advances our comprehension of plasma transport and confinement, establishing a foundational tool for the operational success of ITER and the conceptual design of future fusion power plants.

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Updated Optical Box design for the Erosion Deposition Monitor

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The ITER Erosion Deposition Monitor (EDM) shall observe the erosion/deposition status of the inner and outer vertical targets of the Cassette 22 divertor. The measurement inspects the topology change and surface damage that may occur during the long operation of the tokamak via a Dual-wavelength Digital Holography (DWDH) technique.
Designing the optical box with several mirrors inside under the Divertor dome is the most complex and challenging part of the EDM system, where the box is exposed to structural, seismic, thermal and EM loads. The precise optical components need to transfer with high accuracy diffraction limited images in an environment with thermal deformations, with different operational states. In the meantime, the box structure needs to survive large EM loads acting on the box walls and on the inner components, loading the diagnostic lugs on the cassette body. The largest E-m loads are on the copper components and on the walls with large surfaces. In this way the selection of the proper material and the optimized shape shall handle in the future the large acting forces. Since high nuclear thermal loads act on the box causing high thermal stress: heat shields were designed to reduce the effect of heating. In the meantime, the optical box walls contain complex cooling channels, where the design took into account the manufacturing limitations, the ITER Vacuum Handbook requirements and the high internal water pressure.
In this work several optimization and solutions will be shown to deal with the above-mentioned challenges based on the FEM modelling.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

#13668

Progress Toward Real?Time Pulsed Reflectometry for Plasma Position Control on MAST?U

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Real-time knowledge of plasma position and edge density structure is essential for maintaining stability and protecting plasma-facing components in advanced tokamaks. Looking ahead to STEP and DEMO, microwave diagnostics are expected to play a central role in real-time control because they are robust, compatible with Eurofer-based in-vessel components, and suitable for long-lived integration into next-generation devices. Reflectometry in particular is anticipated to support control of divertor detachment, heat flux, edge density, plasma pressure, MHD activity, and to act as a primary diagnostic for real-time plasma position and shape control. Given this strategic direction, a key step being worked on is the development and demonstration of fast reflectometry on MAST-Upgrade as a pathway toward a STEP-relevant system.

To this end, the University of York, in collaboration with UKAEA Culham, is developing a dedicated pulsed reflectometer for MAST-U aimed at demonstrating microsecond-scale boundary tracking suitable for future real-time control. Pulsed reflectometry determines the cutoff layer from the time-of-flight of short microwave bursts, enabling the plasma boundary to be measured rapidly while effectively “freezing” turbulent motion. Compared with swept-frequency systems, which deliver high-accuracy profiles but are limited by sweep time and sensitivity to fast plasma changes, the pulsed approach offers strong resilience to evolving edge conditions.

This contribution will present the ongoing end-to-end development, calibration, testing, and integration progress of the MAST-U pulsed reflectometer. Current work includes the design and optimisation of a custom front-end optical system, including a compact microwave lens designed to reduce the antenna beamwidth at lower frequencies and enable wider-bandwidth operation. The fast electronics chain for nanosecond-scale pulse generation and digitisation is being characterised in detail, including high-speed ADCs and DACs, to establish timing precision, jitter tolerance, and dynamic range. Following the completion of component-level testing, the next phase will involve full system integration and the development of comprehensive calibration procedures to prepare for in-vessel commissioning on MAST-U.

Initial results from MAST-U experimental campaigns will be presented to demonstrate successful detection of reflected pulses and sensitivity to plasma evolution. These measurements will constitute the first demonstration of pulsed reflectometry operation on MAST-U and provide a foundation for future integration into the real-time position and shape control system.

This work advances fast edge measurement capability on spherical tokamaks and forms a key stepping stone toward robust, low-latency reflectometry systems for next-generation fusion devices.

Real-time ELM energy estimation on ASDEX Upgrade

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The operation of a tokamak in the high confinement mode, as envisioned for ITER and future demonstrator reactors, is often accompanied by rapid and periodic release of particles and energy driven by instabilities on the edge of the plasma. These Edge Localized Modes (ELMs) cause high power depositions on the divertor region, which can lead to permanent damage of these (or other) plasma facing components. It is therefore of great importance to prevent these events or to mitigate their effects. One approach to achieve the latter is to dissipate the ELM energy, by means of injection of impurities, that increase radiation losses before reaching the divertor plates - the ELM buffering effect.
It was previously demonstrated that the measurement of currents of the divertor tiles is a good proxy for the ELM energy deposition. ASDEX Upgrade is equipped with shunts on the divertor tiles, measuring these currents. However the measurements were not available in real-time at a sufficiently high sampling rate. This contribution describes the efforts made to enable the real-time ELM detection and its energy estimation through this method, with the end-goal of creating ELM controller that actuates on impurity injection, and in later stages can also account for confinement degradation due to impurity injection. The implementation of such controller required an overhaul of the data acquisition for the diagnostic, with an increase of the sampling rate to 1 MSPS, as well as the integration of the algorithm in the control architecture. With this integration, the ELM detection with energy estimation can be accessed by other real-time systems or diagnostics via flagged signals.
The real-time compatible algorithm for ELM detection is described. Then, the integration of the algorithm and the new MTCA based hardware in the Discharge Control System (DCS) discussed. Finally, the steps to optimize the parameters for the detection and the estimation of initial control variables ahead of the plasma discharges is shown.

#13689

Automated Sensor Placement & Qualification for Fusion

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Diagnostics & sensing remains a major challenge in the way of economic fusion powerplants. In a fusion plant or test facility, many quantities of interest - such as plasma pressure - are not directly observable. Instead they must be inferred from indirect measurements, often leading to large uncertainties and calibration challenges. These difficulties are expected to increase in reactor-scale tokamaks, where diagnostic coverage will decrease and operating environments will become harsher due to high radiation, thermal, and electromagnetic loads. As a result, the design and placement of sensors is a complex and time-consuming process in fusion.

To address this problem, we apply Bayesian statistics and machine learning through digiLab's Uncertainty Engine, which automatically optimizes sensor placement and qualifies sensors based on observation uncertainty and information gain. In this work, we demonstrate recent applications of this AI-driven sensor placement framework across several fusion sensing problems.

One application involves the placement of thermocouples in tokamak divertors. Thermocouples are robust sensors that do not require direct plasma-facing ports and can provide valuable information on the thermal state and maintenance requirements of plasma-facing components such as divertor cassettes. In collaboration with the University of York, the Uncertainty Engine was used to automatically determine thermocouple locations that maximize knowledge of peak heat loads within a tokamak divertor.

A second application covers the qualification and placement of novel magnetic sensor hardware. In collaboration with supply chain sensor specialists and the UK Atomic Energy Authority, we evaluated new magnetic sensors for potential use in the STEP device. Using genetic algorithms and constrained optimization, these sensors were placed to reduce the uncertainty in key plasma parameters, such as X-point location, while maintaining practical installation constraints. The optimization was performed alongside conventional arrays of magnetic probes, enabling rapid qualification of emerging sensing technologies.

Finally, we applied the framework to redundancy analysis in present-day tokamaks. For the MAST-U device, we find that more than 45% of the poloidal magnetic probe array can experience sensor dropout while degrading sensing performance by only ~3%. These results suggest significant redundancy in existing diagnostics. Future work will test reduced sensor configurations during live operations to experimentally validate this redundancy analysis.

Design and Engineering of the Vacuum Boundary for Diagnostic Integration in JT-60SA

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Topics

E. Diagnostics

Communication type

Poster

Abstract

This presentation reports on the vacuum boundary engineering of diagnostic systems installed in JT-60SA. In preparation for the next operation phase, more than twenty additional diagnostic systems are being integrated into the device. As experimental performance advances, the loads acting on vacuum boundaries exceed those of previous operational conditions. These include high-temperature environments caused by 200℃ baking and plasma radiation, mechanical loads induced by electromagnetic forces, and neutron irradiation. Ensuring the structural integrity and leak tightness of vacuum interfaces under these conditions is therefore essential.

All vacuum boundaries were required to satisfy a helium leak rate below 1×10^{-8} Pa·m^3/s. To achieve long-term stability under elevated temperature and radiation exposure, metal sealing technology was adopted wherever feasible. Elastomer seals were restricted to vacuum window assemblies and electrical insulation sections, considering radiation-induced degradation, and were installed only in locations accessible for replacement.

CF flange standards were employed for vacuum interfaces. In addition, metal hollow O-rings and spring-energized metal C-rings, designed based on CF flange dimensions, were standardized. Surface roughness control of sealing interfaces and bolt torque management procedures were unified to maintain appropriate sealing pressure and reduce cost. For welds subjected to mechanical stresses, full-penetration welding was applied, and structural integrity was verified by radiographic testing. Structural configurations were optimized to mitigate welding deformation.

Installation and helium leak testing were conducted following standardized procedures. To reduce inspection time, a double-seal configuration was introduced, enabling individual self-leak checking of each diagnostic component. This design allows localized verification without requiring full system evacuation for every test, significantly improving commissioning efficiency. No detectable leaks were observed. This presented design methodology provides practical engineering guidance for reliable vacuum boundary implementation in advanced fusion devices.

Final Design of the ITER Radial Neutron Camera Ex-Port System

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The Radial Neutron Camera (RNC) is an ITER diagnostic devoted to the reconstruction of the neutron emissivity profile and the fusion power density throughout a poloidal plasma section. The reconstruction is based on the uncollided neutrons from the D-D and D-T fusion reactions, measured through an array of detectors located at the end of 22 collimated Lines of Sight (LOS), 6 belonging to the In-Port RNC subsystem (covering the plasma section edges) and 16 to the Ex-Port RNC subsystem (covering the plasma section core). The Ex-Port RNC, located in the Port Interspace zone, consists of a massive shielding block that hosts cassettes containing the neutron detectors, positioned at the end of each LOS.

The work presents the Final Design Review (FDR) stage of the Ex-Port RNC, marking the novelties implemented from the Preliminary Design Review (PDR) stage: improvement of detectors accessibility after the VR simulation study of the maintenance procedure; strengthening the mechanical structure after the Final Design FEM simulation results; integration of the Alignment System after the tolerance stack-up analysis and the validation with a dedicated mock-up.

This paper illustrates how the Ex-Port RNC design has matured and been completed from the PDR to the FDR stage, highlighting how the design reached the detailing required from an FDR stage while respecting all the design requirements.

Design and synthetic diagnostic of a vertical multi-energy SXR camera on the WEST tokamak

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Topics

E. Diagnostics

Communication type

Poster

Abstract

A vertical multi-energy soft X-ray (ME-SXR) camera is presently under design for installation on the WEST tokamak. This camera will complement an already installed equivalent horizontal system to provide 2D tomographic reconstruction of the plasma soft X-ray emissivity at different energies. The two cameras employ two identical PILATUS3 pixelated X-ray detectors, in which the lower energy threshold for photon detection can be adjusted independently on each pixel in the range of 2–20 keV. Through meticulous selection of the lower energy thresholds, it is possible to separate signals from line emission and the continuum in order to simultaneously investigate multiple plasma properties. Energy-resolved measurements are used to infer impurity concentrations, Zeff, electron temperature, plasma centroid position, and radiated power density. With the installation of the vertical camera, all these quantities will be determined in 2D and possibly in real time. The vertical camera will allow studying momentum-induced in-out asymmetries of the impurity density, and will provide non-magnetic measurements of the plasma centroid position, determining the Shafranov shift.

This contribution presents the design of the vertical camera. The detector is placed inside a metallic vacuum chamber, which in turn is inserted into a re-entrant shroud installed on a vertical port. A pinhole located after a beryllium vacuum window determines the geometry of the sightlines covering most of the plasma cross-section. A synthetic diagnostic is created using the FAST tool, which simulates the SXR emissivity for typical WEST plasma parameters and impurity mixtures, coupled with the ToFu tool, which computes the camera synthetic signal. In this way, the expected photon count rate on the detector is determined.

Neutron measurements with SiC and Li-Glass detectors within the EUROfusion concrete shielding experiment at the Frascati Neutron Generator

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Topics

E. Diagnostics

Communication type

Oral

Abstract

In 2025, the EUROfusion concrete shielding experiment (EUROfusion Work Package Breeding Blanket) was carried out at the 14 MeV Frascati Neutron Generator (FNG) facility at the ENEA Frascati Research Centre. The general aim of the experiment was to study the neutron transport inside concrete and assess the capability of the Monte Carlo codes to reproduce the experimental results.
Within the experiment, in addition to the activation foils, passive detectors typically used for experiment-to-code comparison, three different types of active neutron detectors were employed: silicon carbide (SiC) detectors, lithium-glass (Li-Glass) GS20-type detectors, and, as an innovative solution, a set of silica-based optical fibres to investigate the potential of this technology for neutron detection.
This work is focused on reporting and discussing the measurements performed with the SiC and Li-Glass detectors. These detectors were deployed to characterize the neutron environment within the concrete mock-up, composed of thirteen concrete slabs with dimensions of $50 \times 50 \times 5$ cm^3. The detectors were positioned at different penetration depths inside the concrete to measure neutron flux attenuation.
Two different SiC detectors were used simultaneously to assess the behaviour of fast and thermal neutrons within the mock-up. The attenuation curve for fast neutrons was obtained by relying on the inelastic $^{12}C(n, \alpha)^{9}Be$ and $^{28}Si(n, \alpha)^{25}Mg$ nuclear reactions occurring inside the bare SiC detector, while the behaviour of thermal neutrons was investigated using the same detector's material covered with a thin layer of ^{6}LiF neutron-absorbing material.
Four identical compact ^{6}Li-enriched Li-Glass detectors were also used during a separate experimental campaign to evaluate their

capability to measure thermal neutrons within the mock-up.
Both detector types were deployed within the concrete at eleven identical positions. The results from the experimental campaigns are presented and discussed through a comparison of the attenuation curves obtained with each detector. Combined with the activation foil measurements, this analysis offers enhanced insight into neutron behaviour in concrete, a key shielding material in nuclear facilities.

#13823

SDD detectors as spectrometers for 14 MeV neutrons: characterization and applications to nuclear fusion devices

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Topics

E. Diagnostics

Communication type

Oral

Abstract

Single-crystal diamond detectors (SDDs) represent the next generation of neutron detectors for spectroscopy in the MeV energy range for fusion applications. Compared to state-of-the-art spectrometers, they have the significant advantage of being inexpensive and compact, and they can operate at high rate at room temperature. They also offer spectroscopic capabilities with energy resolution in the order of 1% at 14 MeV. Finally, they are considered highly radiation-hard and they also have self-diagnostic capabilities, that is important for use in future steady-state machines.

This paper will present the latest characterization results of SDD detectors obtained at CNR-ISTP and associated laboratories, with particular reference to the estimation of the absolute efficiency for 14 MeV neutrons, compared with other neutron detection techniques (based, for example, on the use of activation foils). The studied detectors were constructed from electronic-grade diamond crystals with maximum dimensions of 5 mm x 5 mm x 0.5 mm, assembled individually or in arrays (to increase overall efficiency), and were characterized at different neutron beamlines, such as FNG (ENEA Frascati) and NILE (ISIS, Didcot).

Preliminary results of studies on the expected performance of SDD detectors already planned or simply proposed for the ITER and, in the future, DEMO tokamaks will also be presented.

Homogeneity of a large negative ion beam for fusion by emission spectroscopy

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The homogeneity of large and energetic (up to 1 MeV) negative ion beams for fusion, is an essential parameter to be optimized for ITER. As the energy of negative ion beam increases, the capability to characterize these beams will mostly rely on non-invasive optical techniques based on the collection of the light emitted by the beam itself. The first operations of the full-scale negative ion source SPIDER in multi-beamlet configuration provided the opportunity to assess the capabilities of non-invasive beam diagnostics, such as Beam Emission Spectroscopy, for the investigation of a large negative ions beam. Particular attention was devoted to monitoring how beam homogeneity is affected by machine parameters such as the number of operating drivers and the magnetic filter field. These experimental campaigns have revealed the capabilities and limitations of the current BES apparatus in measuring beam homogeneity, as well as possible strategies to improve this type of estimation. Experimental trends of beam divergence profiles are presented in different experimental conditions. The long-term aim is understand how non-invasive diagnostics can provide a real-time feedback to optimize beam properties, especially in MITICA, the full-scale NBI prototype.

#13830

Spinel based 2D magnetics diagnostics sensors

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The contribution will report on the design of advanced 2D magnetics diagnostics sensors based on spinel (Al2MgO4) with usage Thick Printed Copper (TPC) technology. Materials as Cu and (Al2MgO4) ensures high resistance to temperatures and radiation. The sensor design ensures small size of the sensor to fit in low profile space. The 3D additive manufacturing technology from inconel 718 for the sensor package was used, which brings additional advantages especially in low thickness of package walls leading to low eddy currents. Simulations of signal output in magnetic field and real measurements of sensor response to compare will be presented, same as temperature field simulations to evaluate behavior of sensor outputs related to thermoelectric voltage caused by temperature gradients on sensing coils. Presented version of sensors will be installed on COMPASS-U high field side as part of its magnetics diagnostics system and as test-bed for design of further sensors e.g. for DTT

Performance evaluation/assessment of a mmWave radar system for surface scanning of the IFMIF-DONES liquid lithium target

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The integrity of the 5 MW neutron source in the International Fusion Materials Irradiation Facility DEMOnstration power plant Oriented Neutron Source (IFMIF-DONES) depends on the impact of a high-power deuteron beam on a liquid lithium target flowing at 15 m/s and 300 ºC, whose thickness should be maintained within tight limits (25 ± 1 mm) in order to ensure a safe operation of the facility.

The extreme conditions involved (i.e., nuclear and gamma radiation, high temperature, lithium evaporation) and the need for accurate real-time measuring of the target thickness make radiofrequency diagnostics in the millimetre-wave range a promising safe and feasible solution.

Previous work on this system [1,2] were devoted both to the development of the proof of concept and the execution of some preliminary design and calculations of the radiating element and waveguiding options. Nonetheless, within the scope of conceptual design analysis only the ohmic losses in the waveguides and mode conversion in the mitre bends were considered. Consequently, issues such as sagging in the waveguides, ohmic losses due to the reflection in the mitre bends, offset, and tilting were not addressed. Furthermore, ohmic losses in the circular corrugated waveguides were estimated using the usual wall-impedance approximation, thus lacking a more rigorous approach.

While the analysis presented in [2] was focused on a novel phased array antenna concept, the present work considers different state-of-the-art radiating antennas for a preliminary deployment, evaluating their potential advantages and drawbacks. In addition, more topics should be addressed to progress from the conceptual design to a more mature state. Such topics include the mode conversion from the long-range waveguides to the radiating source and the microwave windows used to isolate vacuum regions.

Finally, the electromagnetic radiating environment of the antennas should also be evaluated. Not only the deuteron beam can be disruptive to the electromagnetic wave of the radar system, but the target vacuum chamber (TVC) can pose a critical threat in terms of cavity resonances, with the potential to compromise measurements, especially when considering a large bandwidth. Despite the considerable electrical size of this chamber, which appears to prevent full wave simulations devoted to this task, measurements in a full size mock-up of the TVC can resolve this issue, which could otherwise prove to be a show stopper.

References:
[1] N. Roy et al., ISFNT-16. 2025
[2] J. Martínez-Fernández et al., Fusion Engineering and Design, 2025.

#13929

Magnetic shielding of the thin-foil proton recoil neutron spectrometer of ITER HRNS

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The main goal of the High Resolution Neutron Spectrometer (HRNS) of ITER is to determine fuel ion ratio in the plasma core, where the Thin-foil Proton Recoil (TPR) spectrometer, as a sub-system, covers high fusion power scenarios. According to the magnetic field distribution maps in the ITER tokamak, the HRNS is located in an area (Equatorial Port #01) where the magnetic field (B) can be as high as 110 mT. Such a magnetic field may degrade the neutron energy resolution of the TPR system.
Performance analysis calculations were conducted to investigate the impact of the static magnetic flux density Bmag on recoil proton deflection and TPR measurements. It was found that while the total proton detection efficiency remains unaffected over a wide range of Bmag values up to about 1 T, the system's energy resolution degrades significantly with increasing Bmag above 50 mT. Below 50 mT, the impact on TPR performance was found to be negligible. Since without any shielding the maximum reachable Bmag is expected to be above 100 mT at the TPR location, the possibility of adding magnetic shielding to keep Bmag < 50 mT within the TPR volume has been studied. Such shielding will ensure that TPR operation and spectrum interpretation will remain unaffected by magnetic field through ITER operation.
Due to the nature of the magnetic field, the shield's operation is based on the principle of magnetic flux shunting in a ferromagnetic material. Such a material should exhibit not only high magnetic permeability but also a high magnetisation saturation. The Ansys Maxwell software was used to design and optimize the magnetic shielding's geometry. Analyses were conducted using the magnetostatic analysis module.
In this contribution, it is shown that magnetic shielding based on ferromagnetic stainless-steel type AISI 430 is expected to decrease the magnetic field below 30 - 50 mT and therefore the impact of residual magnetic field on TPR performance should be negligible.
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Optomechanical and neutronic design of the ITER fast-ion loss detector

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Topics

E. Diagnostics

Communication type

Poster

Abstract

This work presents the final engineering design and integration of the ITER Fast-Ion Loss Detector (FILD) ex-vessel system (Interspace and Port Cell). Moving beyond isolated optical and nuclear analyses, this work details an integrated hardware solution designed to transport high-speed scintillator signals from the plasma boundary to the data acquisition hardware under extreme operational constraints. The design process transitions from theoretical optical concepts to a ready-to-manufacture assembly, where tight space requirements and harsh environmental conditions drive the technical specifications of the final product.

The optical relay has been refined as a high-performance optomechanical assembly, ensuring high-fidelity light transmission over a complex 21-meter path. This system integrates a series of mirrors and lenses specifically engineered to ensure high numerical aperture and resolution requirements with the consideration of manufacturing tolerances and thermal relative displacements. From an optomechanical perspective, the design addresses the critical challenge of maintaining line-of-sight stability under ITER static and dynamic loads. We present the structural solutions for the mirror housings and lens assemblies, focusing on their modularity and their capacity to withstand seismic and thermal events while ensuring long-term functionality.

The system culminates in a Shielded Cabinet that houses the sensitive acquisition electronics, providing a controlled environment within the Port Cell. We provide the detailed mechanical design of this unit, along with the coupled thermal and seismic calculations that validate its structural integrity. Finally, a comprehensive neutronic validation was performed to certify the radiation shielding as a fundamental part of the product's safety compliance. Using SERPENT2 three-dimensional Monte Carlo transport simulations, we assessed the neutron and photon flux attenuation through the cabinet multi-layer configuration. This analysis demonstrates that the final integrated product effectively mitigates radiation streaming through optical penetrations, ensuring the environment remains within specified functional and nuclear safety requirements.

Operational sequence optimisation for ITER First Wall inspection using the In-Vessel Viewing System

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Topics

E. Diagnostics

Communication type

Poster

Abstract

The In-vessel Viewing System (IVVS) is an inspection tool for the ITER plasma-facing surfaces that is resident in the primary vacuum and can be deployed into the vessel to provide viewing and metrology measurements of the first wall. The development of the IVVS to date has focused extensively on metrological accuracy and optical performance, while the transition to inspection of the actual plant requires a deeper understanding of operational feasibility. This report presents a detailed full operation sequence analysis for a simulated inspection of plasma-facing components, including operational time and dose assessment.

The operational sequence is broken down into definition of a target region of interest, splitting the region of interesting into specific deployment positions, focus regions and scanning speeds. This is used to build a scanning strategy via defined waypoints, scan speed and focal configuration optimistion, and a detailed timing assessment that accounts for radiation decay times, self-checks and calibration, robotic deployment, probe location triangulation and scan path. A critical challenge addressed is the optimisation of configuration changes related to speed and focus with optimising the scan density and performance on target. We present an algorithmic solution to automatically optimise the scan strategy for the operator, including provision of simulated scan data matching the scan strategy.

To validate the concept of operation proposed, an analysis is done following the operation sequence. The analysis evaluates the system's damage detection probability for realistic surfaces and damage profiles in ITER using simulated localized damages. This work provides a concrete analysis of the use cases for inspection of damage at ITER, and can be used to improve planning for post-disruption inspections during ITER operations.

Towards a Digital Twin of the VOPOO Diagnostic: Implementation of a Synthetic Full-Wave Framework in REFMULF for Plasma Edge Analysis on SPEKTRE

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Topics

E. Diagnostics

Communication type

Oral

Abstract

The SPEKTRE (Sheaths, Plasma Edge & Kinetic Turbulence Radiofrequency Experiment) platform offers, amongst its broader capabilities, a unique environment to investigate magnetised plasmas at conditions relevant to edge physics in fusion devices [1]. One of its key diagnostics is VOPOO (Variable Oblique Probing on O-mode), a novel microwave diagnostic for oblique and tangential wave propagation at the plasma edge, targeting novel data analysis tools including intensity refractometry and innovative tomographic approaches for plasma shape and position tracking during the ramp-up and ramp-down phases of the discharge. Such capabilities are of particular relevance to next-generation fusion machines such as DEMO.

In this work, we report on the development of a flexible plasma construction method for the VOPOO synthetic diagnostic, implemented in REFMULF, the 2D full-polarisation Finite-Difference Time-Domain (FDTD) code [2]. Building on an initial MATLAB-based proof of concept, the method is now implemented in C language to achieve the computational performance required for deployment on HPC systems. The method converts the polar description of the SPEKTRE plasma column to the Cartesian grid of the FDTD code in a numerically efficient manner, enabling the plasma density to be defined and manipulated before projection onto the simulation grid.

The resulting framework is versatile and numerically efficient, enabling the modelling of a broad range of plasma scenarios entirely at runtime within the FDTD simulation cycle, including the temporal evolution of the plasma through rotation and other dynamic perturbations. The amplitude and phase information at the transmit and receive antennas is essential for validating signal-processing techniques, in particular those applicable to intensity refractometry data, and for driving the development of Machine Learning-based analysis methods.

The 2D REFMULF implementation reported here will serve as the basis for a future extension to full 3D simulations using REFMUL3, which will be essential for accurate phase-amplitude predictions and for validating the tomographic capabilities of VOPOO. Together, these developments mark a significant step towards the construction of a VOPOO digital twin and form part of the broader Reflectometer Digital Twin Environment (RDTE) initiative, targeting integrated physics and engineering simulation frameworks for fusion devices.

[1] F. Brochard et al., 49th EPS Conf. Contr. Fus. Plas. Phys. (2023) P1.098.
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#14080

Broadband pre-matching elements for ITER diagnostic systems with mirror bias voltage measurement output signal

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Topics

E. Diagnostics

Communication type

Poster

Abstract

Efficient operation of a high-frequency plasmatic mirror cleaning system requires proper impedance matching to ensure maximum power transfer to the mirror system with minimal signal loss. This involves matching the standard 50 Ω impedance to the specific impedance of the mirror. This can be achieved using a specially designed circuit acting as a pre-matching network, which can ensure proper impedance matching.

However, the load impedance representing the mirror in the plasma environment exhibits a very low real component of the impedance and a strongly capacitive character (i.e. a high quality factor). This typically leads to the design of a matching circuit operating at a medium frequency, the narrowband design. Due to the operating conditions of the pre-matcher, this can lead to unstable behavior, such as detuning of the circuit and s decrease of the supplied power. Of course, highly restrictive is the environment in which the pre-matcher must operate, therefore no standard industrial components can be used.

This contribution presents two versions of newly developed broadband pre-matchers, that provide significant benefits. Compared with the narrowband design, these pre-matchers are more stable under changing conditions such as high ambient temperature and throughout the device lifetime in a tokamak.

The implementation uses Thick Printed Copper (TPC) technology, which enables robust copper conductors suitable for high-power operation, multilayer capability such as thin-layered capacitors and utilization of metallized vias. This makes it possible to implement more complex circuit topology. In addition, the new circuit design allows extraction of a DC signal from the RF system, enabling in-situ monitoring of the mirror bias voltage during operation, which was not possible with the narrowband version of the pre-matcher.