28th IAEA Fusion Energy Conference (FEC 2020)

Contribution ID: **1408** Type: **Regular Poster**

[REGULAR POSTER TWIN] ITER Plasma Control System Final Design and Preparation for First Plasma

Wednesday, May 12, 2021 12:10 PM (20 minutes)

The Final Design Review (FDR) of the ITER Plasma Control System (PCS) for First Plasma will be held in July 2020 following the conceptual and preliminary designs [1,2] to prepare for First Plasma operation scheduled for the end of 2025. ITER operation follows the Staged Approach of the ITER Research Plan (IRP) [3]. The main goals of the First Plasma campaign include achieving a plasma current Ip > 100 kA for a duration > 100 ms and possibly up to 1 MA for up to 3 seconds duration at half toroidal field of 2.65 T, followed by engineering operation to test the main superconducting coils up to full current. The First Plasma PCS design also includes the full architecture of the PCS that allows implementing high performance control algorithms in the future without changing the PCS architecture.

This phase includes control of the plasma current, radial plasma position, and plasma shape for a nearly circular plasma limited on either the inboard or outboard temporary stainless steel poloidal limiters (Figure 1). Disruption force limits of the attachments of these temporary limiters to the vacuum vessel require control algorithms to ensure that the plasma current remains < 1 MA at the nominal toroidal field of 2.65 T at R = 6.2 m. Following the first plasma attempts at 2.65 T, there will be an engineering operation phase to commission the superconducting central solenoid (CS), poloidal field (PF), and toroidal field (TF) coils to full current, up to 5.3 T nominal TF. If there are difficulties achieving first plasma at 2.65 T, the IRP and the PCS design foresees an option possibly to achieve first plasma at 5.3 T nominal TF. This would be easier than at 2.65 T because of the increased connection length to achieve plasma breakdown and the improved ionization and absorption efficiency of ECH power at the fundamental gyrotron frequency [4].

The plasma initiation phase also includes control of the gas injection of hydrogen to achieve and maintain the required prefill pressure in the range of 0.5 − 1 mPa and the initial density rise as well as the control of electron cyclotron heating (ECH) at 170 GHz. The low startup electric field ˜0.3 V/m, large stray fields due to eddy currents in the vacuum vessel up to 1.5 MA, and the large volume and neutral fueling source limit the allowed prefill range and increase the required power for breakdown. The injected ECH power will be up to 5.8 MW for up to 300 ms from 7 of 8 available gyrotrons from one upper launcher with four beams crossing the breakdown region about 40 cm below the midplane and three beams crossing about 40 cm above the midplane (Figure 1). The beams will be reflected off mirrors mounted to the inner wall into an absorbing beam dump in an equatorial port to avoid scattering stray ECH power around the vessel that could damage in-vessel components. The absorbed power of a single pass is only expected to be of order a few percent of the injected power at half field. Feedback of the prefill pressure timed with the ECH pulses, the PF null, and vertical field swing will be used for robust plasma initiation control. This phase also includes initial exception handling algorithms for possible plant system and diagnostic faults, excess stray ECH power, plasma initiation failures, and start-up runaway electrons.

All control algorithms and synthetic diagnostic models for this phase, including magnetics, H⊠, a single radial chord interferometer, and hard x ray monitor for runaway electrons have been developed in the Plasma Control System Simulation Platform (PCSSP) [5] in Matlab/Simulink for thorough testing in simulation prior to operation.

The PCS design is documented in the PCS database (PCSDB) using Enterprise Architect that records all requirements and tracks their compliance in the design [6]. The controllers are all documented in the PCSDB with explicit links between them and the PCS architecture including supervision, events, and exception handling, which allows checking the impact of any design changes on all aspects of the PCS design. The database includes performance requirements and the test results carried out to assess the design as well as the use cases and commissioning procedures.

Extensive simulations of plasma breakdown and First Plasma scenarios have been carried out with the TRANSMAK [7] and DINA [8] codes including vacuum vessel eddy currents and simplified plasma transport modeling of sputtered impurities from the stainless steel first plasma protection components. The simulations show that plasma initiation is sensitive to the impurity content, but, if breakdown is achieved, the plasma current will rise to ˜ 0.5 MA and by switching the CS and PF voltages to zero, ensure Ip remains < 1 MA to protect vacuum vessel limiter housings.

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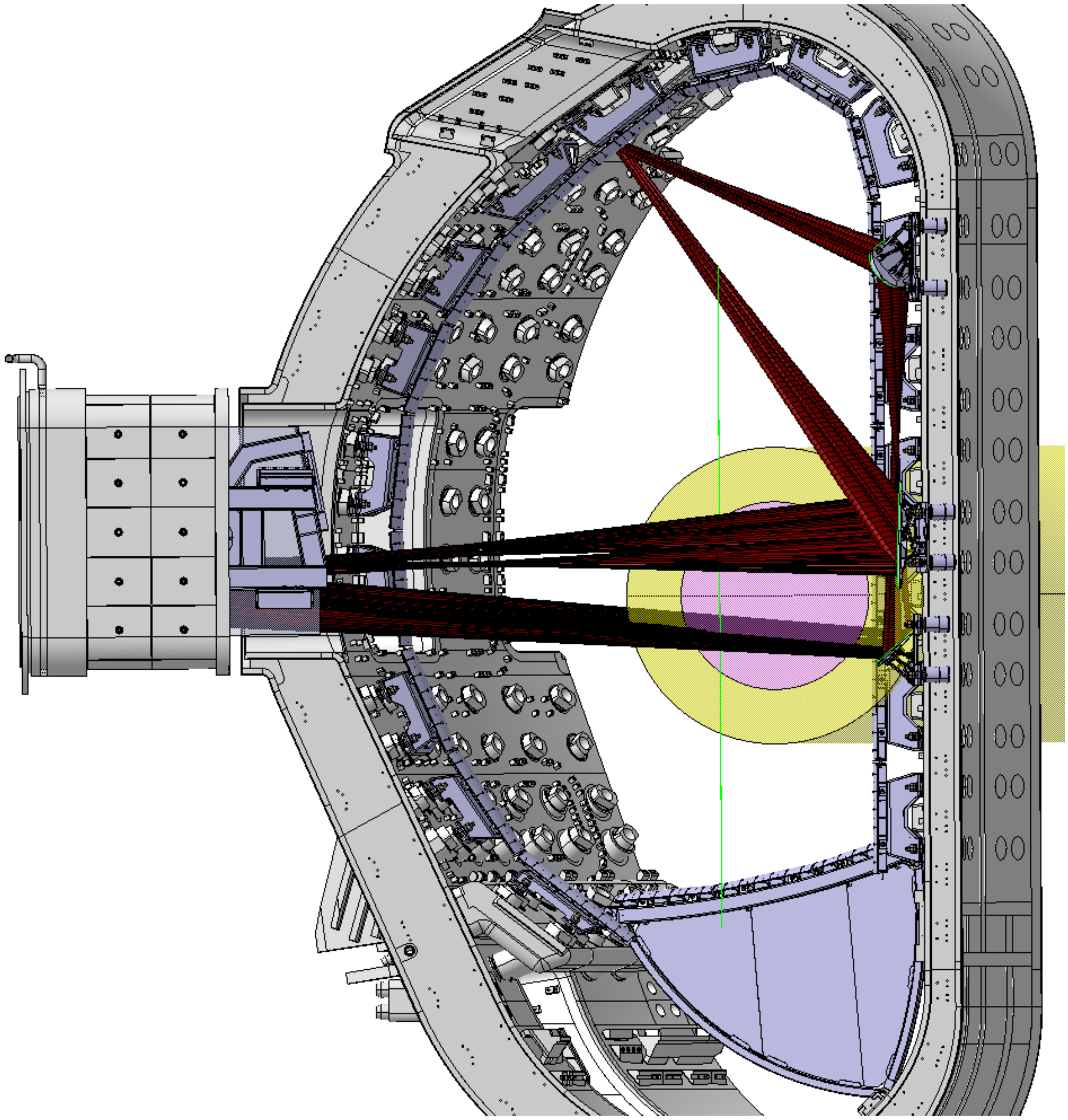

Figure 1: Design of the vacuum vessel showing the stainless steel First Plasma Protection Components including the poloidal limiters, the divertor replacement structure, and the ECH mirrors on the inner wall that reflect the ECH beams from one upper launcher into an equatorial port with an absorbing beam dump. The expected plasma breakdown (pink) and halo current (yellow) regions are also shown

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Session Classification: P3 Posters 3

Track Classification: Fusion Energy Technology