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Impurity seeding for the control of the radiated power using bolometers in Wendelstein 7-X stellarator device

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A future nuclear fusion reactor demands its plasma-facing components (PFCs) to be able to handle the generated heat fluxes. For the divertor to survive continuous operation, mitigating the incoming heat loads is essential [1]. An established approach for reducing the heat loads is by injecting low to medium-Z impurities [2], which stimulates radiation emission in the plasma edge region. Volumetric power dissipation by radiation in the plasma edge reduces the peak heat flux on the PFCs. However, regulating the radiated power requires delicate control. Low radiated power compromises the integrity of the divertor, while excessively high radiated power can provoke an earlier performance degradation. For this reason, a feedback control system is necessary. This contribution discusses the recently operational feedback control system for the radiated power in the Wendelstein 7-X stellarator device (W7-X).
In W7-X the radiation feedback control system was a crucial upgrade. It allowed reliable machine operation despite the challenges with the target/baffle loads in high performance and power conditions. The impurities are seeded by piezo-electric valves [3]. The radiated power proxy is calculated with a specialized wide-angle bolometer camera of only 5 channels [4]. Using feed-forward impurity injection experiments with multi-sinusoidal amplitude modulation allows us to characterize the radiation frequency-resolved response to the actuator [5]. The contribution shows the parameter dependency for density, radiated power fraction (f_rad) and heating power of the transfer functions of the system. The transfer functions are simplified expressions, which provide the timescales and gains, with which the system reacts. The controller design methodology demonstrates the applicability and improvements of the approach for optimized radiation feedback control, which helps to avoid oscillatory behavior.
The controllers operated successfully, allowing for reliable control of the radiated power proxy, both with Nitrogen and Neon. The optimized controller achieves good accuracy with an overshoot in a controller step on the order of 10% and a rise time of less than 200 ms. The feedback system in W7-X allowed reliable operation and accurate control across wide operation parameters. This included challenging high power scenarios and stable detachment (f_rad≈85%)) in a range of W7-X magnetic configurations. The feedback system enabled efficient implementation of long-pulse operation (320 sec,1.2 GJ) in detached conditions and successfully corrected for radiation drifts, likely due to changes in wall outgassing. The remaining challenges for reliable control in the 3D stellarator are toroidal asymmetries in the radiation response due to seeding that have been newly discovered.

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Speaker's title

Mr

Speaker's Affiliation

Max Planck Institute for Plasma Physics, Greifswald

Member State or IGO

Germany

Author: Mr TSIKOURAS, Anastasios (Max Planck Institute for Plasma Physics, Greifswald, Germany)

Co-authors: Dr REIMOLD, Felix (Max Planck Institute for Plasma Physics, Greifswald, Germany); Dr PARTESOTTI, Gabriele (Max Planck Institute for Plasma Physics, Greifswald, Germany); Dr KRYCHOWIAK, Maciej (Max Planck Institute for Plasma Physics, Greifswald, Germany); W7-X TEAM (Max Planck Institute for Plasma Physics, Greifswald, Germany)

Presenter: Mr TSIKOURAS, Anastasios (Max Planck Institute for Plasma Physics, Greifswald, Germany)

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