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SPARC Diagnostics for Use in Plasma Control and Divertor Physics Studies

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The SPARC tokamak is a compact, high-field short pulse device (B0 = 12.2 T, R0 = 1.85 m, τflattop = 10 s) that plans to begin operations in mid-2025. It will execute a series of mission-driven campaigns to close science gaps to inform the design of the ARC fusion pilot plant to begin operation in the early 2030's. Accomplishing this requires a versatile plasma diagnostic set for use in real-time control and inter-shot learning. Diagnostic requirements are driven in part by SPARC's Advanced Divertor Mission, which seeks to answer seven key questions on divertor physics and power exhaust at high, ~10 GW/m2, parallel SOL heat fluxes and edge plasma conditions matching those required for a pilot-plant. Practical constraints limit boundary diagnostic performance, including the timely integration of embedded sensors in a high-temperature, Tlimit ~ 400 degC, high-neutron flux (Pneut/Spl ~ 2 MW/m2), tritiated environment and observing a closed divertor using low-field side, port plug-based measurements.

The full SPARC diagnostic set consists of over 40 sub-systems, multiple of which are relevant for edge and divertor physics. These include magnetics used to reconstruct a range of divertor geometries, main-chamber and divertor neutral pressure measurements, wide spectral range spectroscopy from VUV to NIR to track impurities and characterize hydrogen isotopes, visible and IR camera imaging, bolometry, Langmuir probes, reflectometry for edge density profiles and temperature and strain sensing embedded in PFCs. This contribution focuses on the details of the diagnostics while a companion contribution, "Utilization of SPARC to investigate divertor solutions for fusion pilot-plants"A.Q. Kuang, focuses on SPARC divertor design.

While details of SPARC's diagnostic are subject to evolution, the type and range of anticipated measurements is known. Day-to-day operation will require monitoring and controlling heat flux to plasma facing components. This will use several hundred embedded temperature measurements, mostly via stainless-steel sheathed, Type-N thermocouples, complemented by NIR/IR camera imaging from up to ten toroidally and poloidally spaced imaging port-plugs. Heat exhaust will be mitigated through injection of fuel and impurities, monitored by a 200+ channels of bolometry, micro-Penning and crystal cathode gauges and visible and VUV spectroscopy measurements in the inner and outer divertor. Flux loop and poloidal field sensor probes will reconstruct the x-point and strike point locations, with strike point sweeping employed to spread heat over 10's of cm of poloidal PFC surface, per divertor. Interpretation of these measurements will be facilitated through modeling using the Heat Flux Engineering Analysis (HEAT) toolkit.

Dedicated divertor physics studies, such as determining access to and control of detachment, requires many of the tools used in heat flux control, but pushes requirements on channel count, time resolution and flexibility in observing a range of divertor geometries and conditions. Swept voltage Langmuir probes are not envisioned for high heat flux regions of the divertor, but will be used for novel x-point target geometries that use separate PFC surfaces for strike points. Requirements for visible impurity spectroscopy to enable estimates of tungsten erosion and helium enrichment are also uniquely driven by the Advanced Divertor Mission.

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