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Fast control and data acquisition in the neutral beam test facility

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HIGHLIGHTS

- The paper describes the fast control and data acquisition in the ITER neutral beam test facility.
- The usage of real time control in ion beam generation and extraction is proposed.
- Real time management of breakdowns is described.
- The implementation of event-driven data acquisition is reported.

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ABSTRACT

Fast control and data acquisition are required in the ion source test bed of the ITER neutral beam test facility, referred to as SPIDER. Fast control will drive the operation of the power supply systems with particular reference to special asynchronous events, such as the breakdowns. These are short-circuits among grids or between grids and vessel that can occur repeatedly during beam operation. They are normal events and, as such, they will be managed by the fast control system. Cycle time associated to such fast control is down to hundreds of microseconds.

Fast data acquisition is required when breakdowns occur. Event-driven data acquisition is triggered in real time by fast control at the occurrence of each breakdown. Pre- and post-event samples are acquired, allowing capturing information on transient phenomena in a whole time-window centered on the event. Sampling rate of event-driven data acquisition is up to 5 MS/s. Fast data acquisition may also be independent of breakdowns as in the case of the cavity ring-down spectroscopy where data chunks are acquired at 100 MS/s in bursts of 1.5 ms every 100 ms and are processed in real time to produce derived measurements.

The paper after the description of the SPIDER fast control and data acquisition application will report the system design based on commercially available hardware and the MARTe and MDSplus software frameworks. The results obtained by running a full prototype of the fast control and data acquisition system are also reported and discussed. They demonstrate that all SPIDER fast control and data acquisition requirements can be met in the prototype solution.

1. Introduction

Negative ion neutral beam injectors are required for high-energy neutral beam injection in new generation, high-performance fusion experimental devices [1–3]. Neutral beam injection is typically requested for the whole duration of the plasma that can span from tens of seconds up to 1 h.

ITER will require high-energy (1 MeV in D_2), high-power (16.5 MW) and long-duration (3600 s) neutral beam injection. This operational regime is a scientific and engineering challenge that requires a large R&D program to develop the high-voltage, mechanical, thermic engineering capable to face the many technical and scientific issues that still exist in these additional heating devices.

The ITER neutral beam test facility is this R&D program. Two experiments are under development: the ITER full-size ion source, referred to as SPIDER (Source for Production of Ions of Deuterium Extracted from RF plasma) and the full-size ITER injector prototype, referred to as MITICA (Megavolt ITER Injector Concept Advancement). SPIDER will study the processes related to the ion beam formation and extraction, whereas MITICA will focus on the high-voltage technology and the control of the ion beam acceleration and neutralization.

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SPIDER is currently under construction and is expected to start operation in 2015. MITICA is under design and is expected to start operation in 2019.

This paper will focus on SPIDER whose control system is under test in prototype version.

2. SPIDER control

SPIDER is designed to produce an H^-/D^- ion beam (up to 49/40 A at the grounded grid), accelerated up to 100 keV, and maintained for up to 3600 s.

During the ion beam operation phase, real time control will be applied to drive the SPIDER power supply systems, in detail the radio frequency (RF) power supply, the extraction grid power supply and the acceleration grid power supply, to control the plasma formation within the ion source, the negative ion extraction, and the beam acceleration, respectively.

Gas pressure in the ion source during beam operation will be kept within allowed values by controlled gas injection. Also Cesium diffusion will be controlled by regulating the heating of dedicated Cesium ovens. Temperature of grids and ion source components will be monitored as interference between ion beam and grids can overheat the source mechanical structure and dangerous local overheating may also occur due to acceleration of electron beams (downstream to calorimeter) and back-stream positive ions (upstream to ion source and back plate).

2.1. Slow control requirements

To control the gas pressure within the ion source during beam operation a real time pressure reference signal will be generated by the SPIDER Control and Data Acquisition System (CODAS). This pressure reference will be tracked at plant unit level using as feedback signal the gas injection line pressure. At the beginning of the SPIDER experimental phase gas injection will be controlled from SPIDER CODAS in open loop, most probably by requesting a constant pressure value within the vacuum vessel, whereas closed loop control, at SPIDER CODAS level, will be possibly applied in a second experimental phase. Gas injection will be driven by slow control (typical cycle time 10–100 ms). Cesium oven control and monitoring of temperature of ion source mechanical components will also be a typical slow control task, as analog bandwidth of thermal signals is low due to thermal capacity of components.

Slow control will require no special techniques.

2.2. Fast control requirements

At the beam start-up the plasma will be ignited by feeding a filament and then sustained by radio frequency (1 MHz). The acceleration potential (−100 kV) will be applied to the source and, as soon as voltage is applied on the extraction grid, negative ion extraction starts and the negative ion beam is accelerated. The plasma grid will also be powered to create a flowing current that, through its magnetic field, produce a magnetic filter to favor extraction of negative ions and adverse extraction of electrons.

In principle the neutral beam injector is required to operate in steady-state, but slow control is not suited to control the SPIDER fast power supply systems. In fact, the insulated-gate bipolar transistor based power supply systems require cycle times of the order of hundreds of μs in response to possible fast changes of load. An event typically causing fast load modification and electrical stress on the power supply systems is the breakdown, i.e. a short circuit, typically sustained by arcs, between grids or between grids and vessel. Breakdowns cannot be considered as faults in neutral beam injectors, as they may occur repeatedly and routinely with frequency up to tens of events per second.

When a breakdown occurs, the acceleration and extraction grid power supplies must be switched off to avoid overcurrent and arc feeding. A fixed time is then waited for (breakdown dead time, typically 20 ms), to allow insulation recovery. Successively voltage can be progressively re-applied to acceleration and extraction grids. Radio frequency power supply must be also controlled timely by reducing the output voltage to a predefined voltage level referred to as notch value. Radio frequency power supply cannot, in fact, be switched off to avoid plasma loss in the ion source. From the value of breakdown dead time, the maximum breakdown frequency will be up to 50 Hz.

The detection of the breakdown will be implemented by means of fast electronics and breakdown occurrence will be notified in parallel to the power supply, Interlock and CODAS systems to implement reliable, redundant protection. The breakdown notification to the power supply system serves to stop immediately and reliably the power supply systems (within 1 μs) whereas the breakdown notification to the Interlock System serves in case of anomalous repetition of breakdowns due to persistent short-circuit faults. In addition to reference waveform management, on occurrence of breakdowns CODAS will check the breakdown frequency and the total number of breakdowns occurred since the beginning of the beam pulse. Abnormal termination of the beam pulse will be executed in the case of exceeding of preset thresholds (typically breakdown frequency exceeding 10 breakdown/s and total number of breakdowns in one single ion beam pulse exceeding 200 events).

Fig. 1 shows the typical waveforms of RF power, extraction grid power supply (EGPS) voltage, plasma grid filter power supply (PGFPS) current, bias plate power supply (BPS) voltage and extraction/beam current. Dotted lines refer to where real time control can be applied to optimize the beam start-up and breakdown recovery.

Breakdown management is not, however, the only reason to implement a real time fast controller to drive the power supply systems in SPIDER. In fact, management of power supplies without intervention of SPIDER CODAS could be implemented by presetting a set of parameters (such as post-breakdown recovery voltage

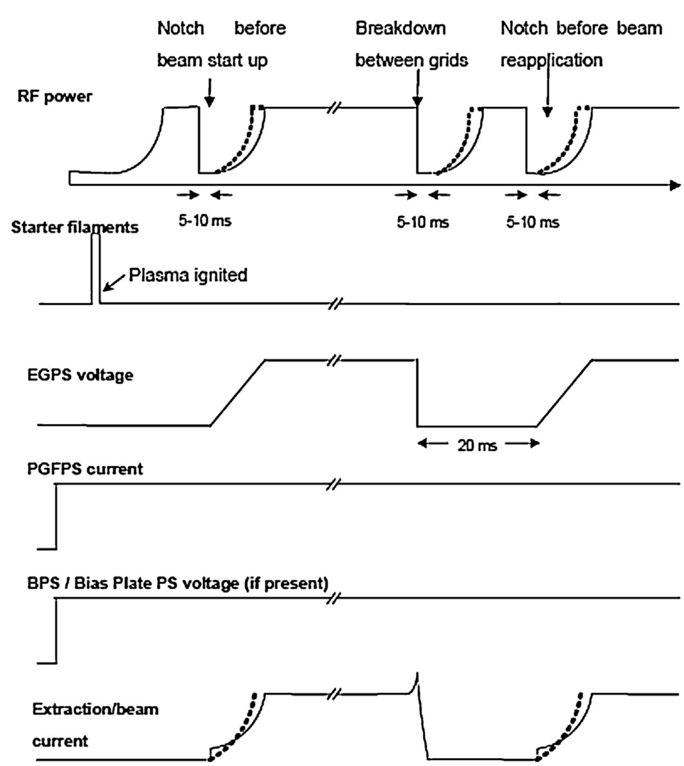

Fig. 1. Typical reference waveforms for the power supply systems.