CONTROL AND DATA ACQUISITION FOR ITER ION SOURCE TEST BED

A. Luchetta, O. Barana, A. Barbalace, G. Manduchi, A. Soppelsa, C. Taliercio,
Consorzio RFX- Euratom-ENEA Association, Corso Stati Uniti 4, I-35127 Padova, Italy

Abstract

SPIDER is a test bed under development in Italy, to start operation in 2013, for developing the full size negative ion source for the ITER heating and diagnostic neutral beam injectors. A set of diagnostics will measure the source and beam parameters, including thermocouples, calorimetry, emission/absorption spectroscopy, electrical, vacuum, radiation, caesium sensors. The paper presents the requirements and the design of the control and data acquisition system, illustrating the design criteria and technological choices.

INTRODUCTION

The ITER plasma current will be driven in steady-state and its plasma heated up to ignition by dedicated additional heating and current drive systems based on the injection of radio frequency power (ion cyclotron, electron cyclotron, lower hybrid) and neutral beams in H or D obtained by accelerating negative ions successively neutralized. To reach the required operational scenarios, the performance requirements for the ITER Heating Neutral Beam Injectors (HNB) (beam power 16MW, energy up to 1MeV, beam-on time up to 3600s) are far beyond the parameters of existing injectors [1,2,3]. Moreover, due to maintenance advantages, ITER has selected the innovative approach of radio frequency ionization [4], as the technology to ionize the gas in the ion source. For the reasons mentioned above, ITER will support the development of the HNBs by an ad-hoc Neutral Beam test facility, to be constructed in Padova, Italy that will include two test beds. The first one, referred to as SPIDER, will be targeted at developing the ITER full-size ion source, whereas the second one, referred to as MITICA, will focus on the development and test at full performance of the ITER neutral beam injector. To comply with the ITER schedule, SPIDER is expected to start operation in 2013, whereas MITICA in 2015.

This paper focuses on the control and data acquisition system of SPIDER, and describes the requirements for the system design, the system architecture along with some technological details.

SPIDER OVERVIEW

Figure 1 shows the conceptual scheme of the RF source. Gas (H_2 or D_2) is fed into the drivers and ionized by radio frequency produced by MHz current circulating in the RF coils. Plasma diffuses into the main chamber where Caesium (Cs) is evaporated and deposited on the chamber inner surface and the grids. Cs deposition reduces the material work function, and negative ion production yield on surface is increased. The ion extractor and accelerator comprise three grids: Plasma Grid (PG), Extraction Grid (EG), and Grounded Grid (GG). The EG and GG are fed at the acceleration (nominally -100kV) and ground potential, respectively, so as to accelerate the negative ions in the direction of the voltage gradient. The PG is polarized at a negative potential (extraction voltage down to -12kV) with respect to the EG and a magnetic field is produced by a vertical current up to 5kA in the PG (PG filter current), to reduce electron temperature and the number of co-extracted electrons. Permanent magnets optimize the magnetic field distribution close to the PG to aid reject of electrons. The accelerated ion beam is targeted at a beam stopper (calorimeter) that can withstand the deposited power.

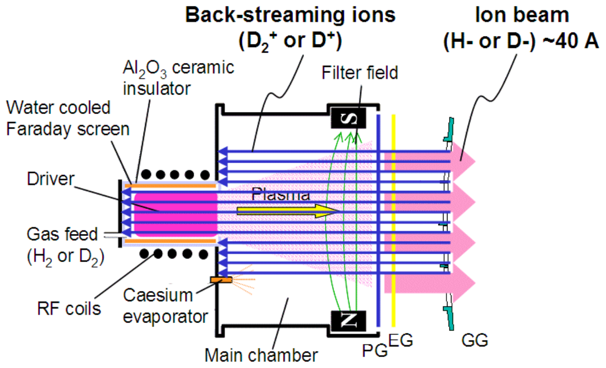

Figure 1: Operating principle of the ion source.

SPIDER SYSTEM REQUIREMENTS

Performance Requirements

The nominal performance requirements of SPIDER are: Ion beam in H^- or D^-; Beam energy 100keV; Extracted ion current 64/57A in H^-/D^-; Beam on time 3600s; Beam uniformity ±10%; co-extracted electron fraction e^-/H^- or e^-/D^- less than 1.0 /0.5 in H^-/D^-.

Operation Requirement

Though SPIDER is required to demonstrate beam operation up to 3600s, most experimental pulses are expected to last only up to 600s, which is the time to reach steady-state conditions in the test bed. At the beginning of the pulse sequence H_2 or D_2 is injected into the drivers and the power supply for the PG filter current is switched on. Then starter filaments are switched on and the plasma is ignited by the RF power. After plasma ignition, the starter filaments are turned off. Then the RF power is increased to the nominal value, successively reduced to a lower value (10-20% of rated power) and finally reapplied as the voltage is applied on the EG, to extract and accelerate the negative ions produced in the

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source. The PG is heated to 250-300°C to enhance the Cs effect of surface production of negative ions.

The grids in the extractor operate close to breakdown and during normal operation grid breakdowns may occur frequently and unpredictably. The grid breakdown is not a fault, even if it stresses the power supplies and requires interruption of the operation. On breakdown occurrence the power on the EG has to be turned off (max delay 100us), the RF power reduced to about 10% of the rated value for about 5-10ms, then, the RF power is ramped up again to the value preset before the event.

Modulation of the beam power is required at 5Hz (100ms ON, 100ms OFF) for 3s every 20s, resulting in modulation on the extraction voltage and RF power.

To reach normal operation, the ion source has to be properly conditioned by conditioning procedures. These are receipts that are empirically set up and typically consist in three phases: Grid conditioning (breakdown optimization); Plasma source conditioning (ionization optimization); Beam conditioning (beam optimization).

Control and Data Acquisition Requirements

The operation of the test bed requires the coordination of multiple functions (vacuum pumping, heating and cooling, gas supply, Cs deposition, and power supply) and careful monitoring of component limits (temperatures on the grids, calorimeters, and injected and removed power). Most functions, e.g. vacuum pumping and cooling, can be controlled by using industrial slow controllers operating with cycle time around 10-100ms or larger, whereas the power supply requires fast controllers with cycle time down to about 100us. A set of diagnostics will measure the source and the beam parameters. Some measurements will be used in control, e.g. coolant temperatures and flow rates for the beam source and line components, Cs oven temperatures, beam source and line temperatures, cryopump temperatures, vacuum measurements in the beam source and Gas flow, cooling water conductivity. Other measurements will characterize the plasma and the beam, such as residual gas analyses in the injector's volume, Doppler shift measurement of the beam profile, density of electrons, ions, neutrals and impurities in the source, temperature of electrons, ions and neutrals in the source, electrical plasma parameters, plasma light, visible and infrared imaging of components inside the vessels.

Most signals, such as thermocouples, require a low sampling rate (< 50S/s); A few hundred signals require an intermediate rate of up to 200kS/s; Some tens of signals require high rate of up to 1MS/s, as for instance some high-bandwidth electrical signals; A few signals need to be sampled at a very high rate (100MS/s), such as the cavity ring-down. In addition, imaging diagnostics will acquire around 70 frame sequences with a rate up to 1kHz for the whole beam duration.

CONTROL AND DATA ACQUISITION

The system layout is depicted in Fig 2. The presentation layer presents an abstraction of the experiment to the operators and scientists. The data handling layer handles data storage into a long-term archive, data access, and analysis. The control layer controls the test bed, by process automation and plant monitoring (A&M), by fast control (Real-time Control), and by generation and distribution of the time reference. The plant layer includes all plant units (PU) and diagnostics installed in the experiment. According to their nature, plant units are grouped into four plant subsystems: Beam Source (B), Technical Supply (T), General Services (G), and Power Supply (P). A&M is in charge of the execution of automatic and semiautomatic sequences as well as the plant supervision to ensure that the plant operating limits are not exceeded. The real-time system controls those

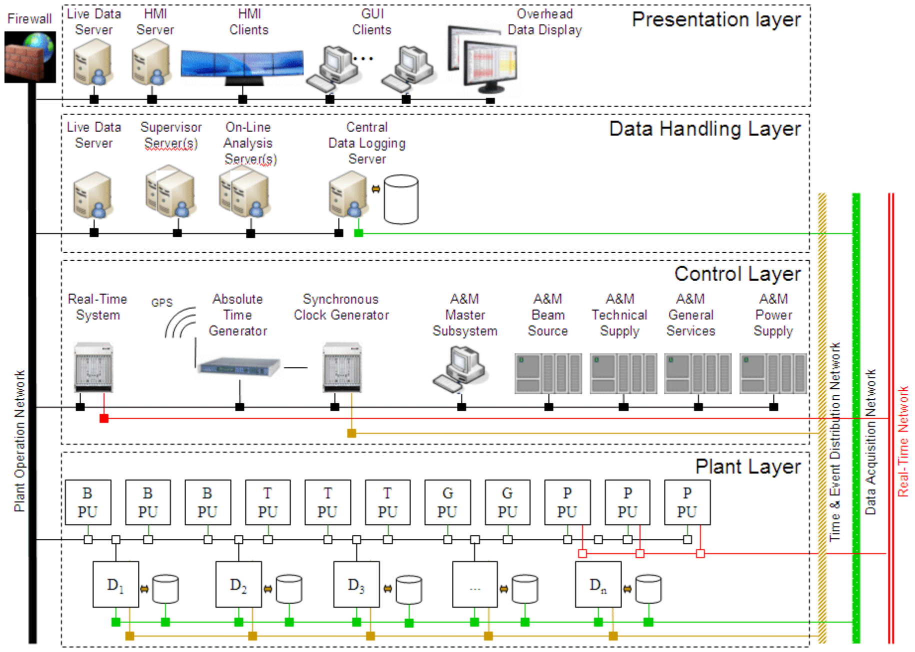

Figure 2: Architecture of SPIDER control and data acquisition system.

components that require cycle times down to hundreds of µs, as is the case for the generation of the reference waveforms for the power supplies. A&M is organized in four subsystems corresponding to plant subsystems, plus one master subsystem. Subsystems B, T and G will be involved in slow operation, requiring therefore a data sampling rate of around 10-100Hz. These subsystems are not different from traditional industrial plant systems, and will be managed by PLCs. A variety of SCADA systems is available on the market for plant control and monitoring, and a survey [5] has been carried out at Consorzio RFX comparing the performances of two commercial (PVSS II by ETM [6], and FactoryTalk by Rockwell Automation [7]) and two Open-Source SCADA systems (EPICS [8] and TANGO [9]). The outcome of that work was that both PVSS and EPICS represent viable solutions. EPICS has been then selected as a consequence of the decision of ITER to adopt this system. Subsystems P and the diagnostics will require also fast control and higher data acquisition rates. The long duration of the beam pulses, compared to the typical duration of the plasma discharge in current fusion experiments, introduces new stringent requirements in both data transfer throughput and storage space. Several physical phenomena to be studied, such as the occurrence of a breakdown event in an accelerator grid, have a bandwidth of up to several MHz, thus potentially requiring a huge amount of storage space if these signals are to be acquired at full rate for the whole pulse duration. The events of interest, however, do not occur continuously. Rather they may happen randomly during the pulse. Therefore a data acquisition system able to acquire signals at a lower sampling rate outside the events of interest, and to switch to a much higher rate in a time window centred around the occurrence of the event of interest would provide an acceptable trade-off between the need of storing all the needed information and the limited availability of storage space. This can be achieved by duplicating data acquisition, using a first ADC to provide continuous data sampling at a baseline frequency and a second one that is triggered at every event occurrence to provide fast acquisition in a time window centred on the event time. A more flexible solution would be provided by developing a new ADC architecture, able to provide continuous baseline data acquisition and able to switch to higher frequency upon the occurrence of a given event. To note that providing a multi speed sampling clock is not a feasible solution, as the generation of event triggers will be affected by unavoidable delays. Rather, the ADC should sample continuously at high frequency, and an appropriate FPGA data management has to ensure that (filtered) data are decimated outside event time windows. The solution using duplicate ADC channels is ready on the market and will be implemented in SPIDER initially. A development activity is ongoing to provide an implementation based on a single ADC, which would also introduce a higher degree of flexibility, such as the real-time detection of the event itself.

In order to provide the required support for distributed data management, the usage of MDSplus is foreseen. MDSplus is in use in many fusion experiments and provides both support for distributed databases and continuous data acquisition. MDSplus in SPIDER will provide complete data management, from ADC and frame grabber readout up to data presentation and graphical visualization. MDSplus would suffice for the whole data acquisition management, however, in order to gain experience and possibly reuse system components for the MITICA test bed, we plan also to integrate the ITER CODAC supervision interface to SPIDER. To this purpose, in 2010 a beta version of ITER Mini-CODAC will be tested in Padova. MiniCODAC is a tool developed at ITER to simulate the real CODAC system to which the plant host is interfaced to, and is intended to provide a first level of acceptance before the on-site acceptance test.

CONCLUSIONS AND FUTURE WORK

The overall architecture of the Control and Data Acquisition system of SPIDER has been presented. Programmable Logic Controllers will be adopted for the conventional parts of the system, and EPICS will be used for supervision and slow control, as prescribed in ITER. More challenging requirements come from data acquisition for power supplies and diagnostics, where high bandwidth for particular events during the pulse needs to be carefully handled. The proposed approach for event driven data acquisition represents an acceptable trade off between high requirements and the limited availability in data throughput and storage.

REFERENCES

[1] Y. Ikeda et al., “Present status of the negative ion based NBI system for long pulse operation on JT-60U”, Nucl. Fusion 46 No 6 (2006) S211-S219.

[2] K. Ikeda et al., “Recent Progress of Neutral Beam Injector and Beam Emission Diagnosis in LHD”, Plasma Sci. Technol. 11 No 4 (2009) 452-455.

[3] A. Staebler et al., “Development of a RF-driven ion source for the ITER NBI system”, Fus. Eng. Des., 84 (2009) 265-268.

[4] E. Speth et al., “Overview of the RF source development programme at IPP Garching”, Nucl. Fusion 46 No 6 (2006) S220-S238.

[5] O. Barana et al., “Comparison between Commercial and Open-source SCADA Packages - a Case Study” to appear in Fusion Engineering and Design.

[6] Rockwell Automation home page [Online]: http://www.rockwellautomation.com.

[7] ETM home page [Online]; http://www.etm.at.

[8] EPICS home page [Online]; http://www.aps.anl.gov/epics.

[9] TANGO home page [Online]; http://www.tango-controls.org.

[10] T. Fredian, J. Stillerman, ”MDSplus. Current developments and future directions”, Fus. Eng. Des. 60 (2002) 229-233.