IFMIF EVEDA RFQ LOCAL CONTROL SYSTEM: POWER TESTS*

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Abstract

In the IFMIF EVEDA project, normal conducting Radio Frequency Quadrupole (RFQ) is used to bunch and accelerate a 130 mA steady beam to 5 MeV. RFQ cavity is divided into three structures, named super-modules. Each super-module is divided into 6 modules for a total of 18 modules for the overall structure. The final three modules have to be tested at high power to test and validate the most critical RF components of RFQ cavity and, on the other hand, to test performances of the main ancillaries that will be used for IFMIF EVEDA project (vacuum manifold system, tuning system and control system). The choice of the last three modules is due to the fact that they will operate in the most demanding conditions in terms of power density (100 kW/m) and surface electric field (1.8*Ekp). The Experimental Physics and Industrial Control System (EPICS) environment [1] provides the framework for monitoring any equipment connected to it. This paper report the usage of this framework to the RFQ power tests at Legnaro National Laboratories [2][3][4].

INTRODUCTION

The main objective for IFMIF (*International Fusion Materials Irradiation Facility*) is the construction of a linear accelerator for neutron irradiation effects on materials that will be used to realize future fusion reactors. The facility will provide an accelerator-based neutron source that produces, using deuterium-lithium nuclear reactions, a large neutron flux with a spectrum similar to that expected at the first wall of a fusion reactor (Fig.1).

The main components of the apparatus for the neutron beam production are therefore the following:

- the generation system of deuterons, consisting of two linear accelerators in parallel each producing a current of 125mA beam and made up of an ion source, a low energy beam transport system (LEBT) which guide the beam from the accelerator source to the radio frequency quadrupole (RFQ), a medium energy beam transport (MEBT), superconducting cavities and a high energy beam transport (HEBT);
- the system constituted by the target in the lithium and the associated circuit for the evacuation of the produced power;
- test cell inside which are arranged the samples of the materials to be tested.

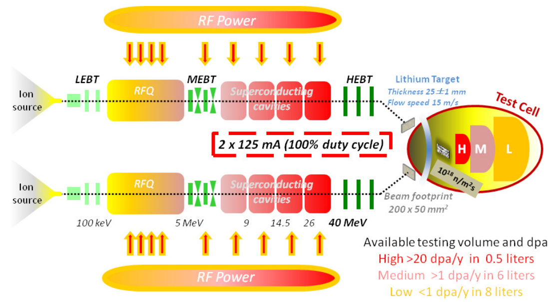

Figure 1: IFMI facility architecture: two parallel accelerator lines provide the final beam required for the production of deuterium-lithoum nuclear reactions**.**

Because of the complexity of the project, its implementation requires a preliminary step related to the validation of the prototype. For this reason, IFMIF-EVEDA (*Engineering Validation Engineering Design Activities*) involves the construction of prototypes of three different components mentioned above.

In this scenario, INFN-LNL contribution consists on the construction of the RFQ system: in according to the specifics required by the project, the RFQ apparatus results to be one of the most powerful machines in the world, due to manage deuteron beams at high energies (125mA deuteron beam in continuous wave (CW) up to 5MeV). As consequence, the RFQ Local Control System (LCS) has to implement all the services and features required in a control system and, at the same time, following the project requirements in order to optimize the integration in the final main control system during the commissioning phase.

RFQ LOCAL CONTROL SYSTEM ARCHITECTURE

The RFQ Local Control System (LCS) Architecture approved by the IFMIF-EVEDA Collaboration has been designed to optimize the reliability, robustness, availability, safety and performance minimizing all the costs related to it (purchase and maintenance). Following this philosophy and the IFMIF-EVEDA Guidelines, we proposed to realize a control system network composed by two different kinds of hosts:

- Physical machines for critical control system tasks;
- Virtual hosts in machines where no particular functional task or hardware is required.

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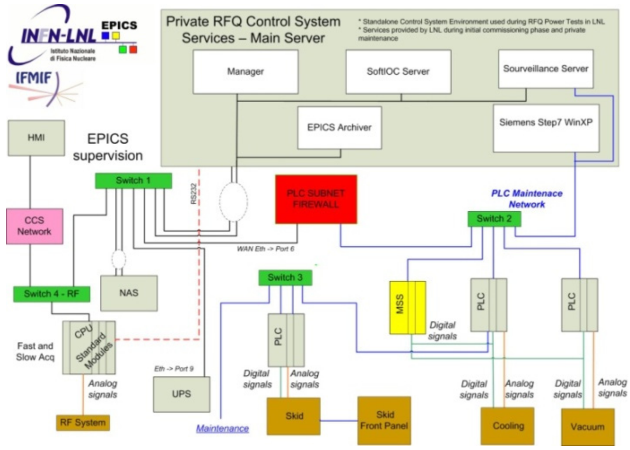

Figure 2: RFQ Local Control System Architecture.

The architecture, visible in Fig. 2, realizes the 3-layer structure described in the Guidelines and each layer defines a proper hosts group (equipment directly connected to the apparatus, control devices, Human-Machine Interface) while the EPICS framework provides the interface between them.

Minimal modification has been made after the RFQ power test for fixing minor bugs found and optimize communications among the different sub-systems.

LCS CORE SYSTEM – HARDWARE AND SOFTWARE

The basic idea followed during the LCS design and implementation was having a complete control system available for the RFQ apparatus during power test in LNL and easily to integrate during the commissioning in Japan. A key enabling technology for this is the virtualization and the provisioning through KVM [5] and Cobbler [6]. These software are completely supported under the RedHat Enterprise Linux (*RHEL*) Operative System and used in a wide range of network system solutions and this approach allows the installation saves floor space, power, and cooling per unit of processing capacity. In addition, operations, administration, and maintenances can be addressed more efficiently and less expensively.

For having a robust system, server's disks are setup with hardware RAID and use the Logical Volume[7] feature to partition.

The hardware used to perform the control system was placed in dedicated cubicles, as visible in Fig. 3: each cubicle contains a different set of devices and, according to the requirements for the power.

Under software aspects, several services has been implemented through virtual machine technology in order to provide a complete standalone control system for the RFQ apparatus:

- **Archiver**: an EPICS RDB (Relational DataBase) Archiver with PostgreSQL Database has been and the data retrieval operation is implemented inside the GUI system which is CCS (*Control System Studio*) for this project.
- **Deploy and backup**: the manager machine is designed to realize, through appropriate open source applications and services, an automated management for new machinery's configuration inside the RFQ LCS.
- **Surveillance**: in the local control network OpenMonitor Distribution (OMD) solution[8] was chosen to perform this task. One of the most interesting features of the software is the total customization of monitoring system through dedicated plugins; in this way the operators can have all the information of interest desired.
- **Project Management Document Server**: widely used and recognized tools in Open Source development, Subversion (SVN)[9] and Bugzilla[10], have been proven to be suitable for most kind of software projects and have lately been accompanied in many projects with an emerging document and content management system, Wiki[11].

  EPICS softIOCs virtual server: a properly configured virtual machine equipped with the entire EPICS environment is developed. This machine is created for realizing a EPICS IOC for every device and system which require it and providing a Boot Server for the VME system in charge of realize the RF acquisition.

Figure 3: RFQ Racks preparation for power test.

LOCAL CONTROL SYSTEM

The system has been designed and realized using PLC hardware is chosen in tasks where security is the most critical feature while VME system is used where the acquisition speed rate is crucial and common hardware (such as embedded systems) is chosen when only integration is required, without any particular feature in terms of security. In this scenario, The fast acquisition is based on VxWorks real time OS which run over a VME architecture. The most important channels: direct, reflex, and cavity power are sampled with a maximum rate of 1000KEvents per second. The absence of low level RF makes necessary a use of a signal generator to the power tests.

For this reason, an EPICS driver has been written to

integrate that instrument to these tests. The vacuum and cooling control systems are based on PLC software while the EPICS framework is on charge of providing the interconnection to HMIs, archiving and alarm managements. In both sub-systems controls are based on SIEMES S7-300 PLC. The surface temperature of a RFQ has never been analyzed before on other RFQs; we tried to map the temperature distribution along the RFQ with a high
defined mesh, saving a wiring effort and at the reasonable price. 1-Wire® devices satisfy this approach, providing simple and cheap technology; for this kind of device, an EPICS driver is developed to integrate this solution into the control system. IFMIF-EVEDA requires a system to measure the micro bunch length. A slim embedded solution with the needed ADCs/DACs is enough to this measure. Above this hardware, dedicated EPICS IOCs running on virtual and physical hosts manage the different sub-systems.

In this final stage, the entire EPICS control system is composed by about 1150 PVs in 6 IOCs. As shown in Table 1, part of these variables must be archived and monitored by the archive and alarm systems.

Table 1: Main Information Related EPICS RFQ LCS

Number of	Power Test
IOCs	6
DBs	17
PVs	1153
Channel Archived	970
GUIs	15

The Graphical User Interface (GUI), developed in Control System Studio (CSS) [12], is composed by a set of panels which let scientists remote control the apparatus (Fig 4): main panel gives the global view of the experiment, while specific panels and pop-up windows, divided according the subsystems, give detailed information.

POWER TEST

A partial test at full power and CW duty cycle has been performed at INFN-LNL on the last elements of the RFQ. The high power test gave us the opportunity to validate all the LCS parts in conditions similar to the operative ones, fixing bugs and making modifications when it was necessary. Closed loop controls are crucial parts in accelerator operation. For the power test we set-up several close loop controls:

- Frequency Follower Control (FFC), to set the output frequency of the RF amplifier at the natural frequency of the RFQ.
- RF power Level Control (RLC), to maintain constant the power inside the cavity.
- Temperature control of cooling water circuits.
- Resonant Frequency Control (RFC) to control the cavity natural frequency by means of the cooling water temperature. In the final installation FFC and RLC will be provided by the Low Level RF (LLRF) system developed by CIEMAT. Nevertheless power test gave us a deeper knowledge of the functions and performances required for the LLRF system. Controller set-up and tuning was one of the mostly time consuming activity.

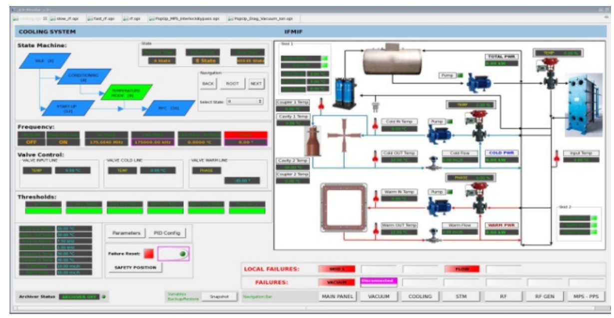

Figure 4: Example of GUI for RFQ Power Test.

Thanks to the power test, we have now a valid procedure to operate the tuning of the cavity frequency controller, which will be manually carried out also at Rokkasho. We also collected, by the LCS users, significant feedbacks about the use of the CSS GUI (Graphical User Interface) and the data archive (Fig. 5).

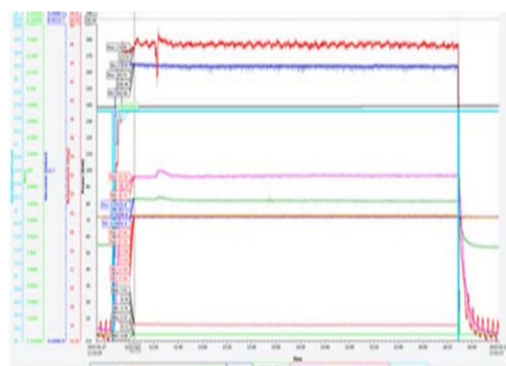

Figure 5: Data Archiver through EPICS RDB Archiver.

CONCLUSIONS

Preliminary tests on the singular control system tasks are done with positive results and every subsystem reaches the expected objectives. Because of the importance of the power tests for the RFQ apparatus, this is a great test bench for the entire control system architecture in order to debug the core system and a good feedback for the work realized by the team.

An exhaustive test with the entire apparatus has not been executed but it will be performed when the RFQ will be in Rokkasho: in that stage we will be able to check if the system modularity will cover all the specifications required by the acceptance tests provided by the agreements with Fusion for Energy (F4E).

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