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CONTROL AND FUNCTIONAL SAFETY SYSTEMS DESIGN FOR REAL-TIME CONDITIONING OF RF STRUCTURES AT TEX

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Abstract

We report the status of the development of an High Power RF Laboratory in X-Band called TEX (TEst-stand for X-Band). TEX is part of the LATINO (Laboratory in Advanced Technologies for INnOvation) initiative that is ongoing at the Frascati National Laboratories (LNF) of the Italian Institute for Nuclear Physics (INFN) that covers many different areas focused on particle accelerator technologies. TEX is a RF test facility based on solid-state K400 modulator from ScandiNova with a 50MW class X-band (11.994 GHz) klystron tube model VKX8311A operating at 50 Hz. This RF source will operate as resource for test and research programs such as the RF breakdown on RF waveguide components as well as high power testing of accelerating structures for future high gradient linear accelerator such as EuPRAXIA and CLIC. In this context we will present the whole EPICS control system design focusing on archiving, user interfaces and custom development made as part of the functional safety to deliver real-time RF breakdown detection integrated with the timing system of the facility.

INTRODUCTION

In preparation to the activities of the EuPRAXIA@SPARC_LAB projectand the LATINO (Laboratory in Advanced Technologies for INnOvation) Initiative, a high-power test stand for X-band accelerating structures called TEX ("TEst stand for X-band") [1] is being built at LNF.

The X-band (11.994 GHz) is at present the most advanced RF technology, with demonstrated capability of providing accelerating gradients up to 100 MV/m and beyond. In this context started the implementation of a new high power X-band test stand at LNF. The area to host the new test stand within the LNF has been identified and it is presently being refurbished to provide all the required services to the facility. The concrete bunker shielding the accessible area from the radiation produced by the structures under test is also being designed and constructed.

The facility under commissioning [2] will be used for testing X-band accelerating structure prototypes (EuPRAXIA [3] and CLIC projects), RF components and sub-systems. For the rest of the time the facility will be accessible to external users, including national and international laboratories and companies.

The open-access to TEX is one of the services offered by INFN to the external community through LATINO [4], a project approved and funded by the government of "Regione Lazio" aimed at promoting and increasing the technology transfer between research centres of excellence and the surrounding economic framework.

In this document the TEX Control System will be presented with special reference to tier architecture and user tools.

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CONTROL SYSTEM FRAMEWORK

The control software (CS) framework called EPICS (Experimental Physics and Industrial Control System) [5] provides an architecture for control system software to be constructed as a scalable, distributed database of control components. It is based on industry standards at all levels and includes an extensive set of tools and clients that are portable across all major architectures. TEX has selected a standardised, field-proven controls framework, EPICS, which was originally developed jointly by Argonne and Los Alamos National Laboratories, Figure 1. Complementing this selection are best practices and experience from similar facilities regarding platform standardisation, control system development and device integration and commissioning.

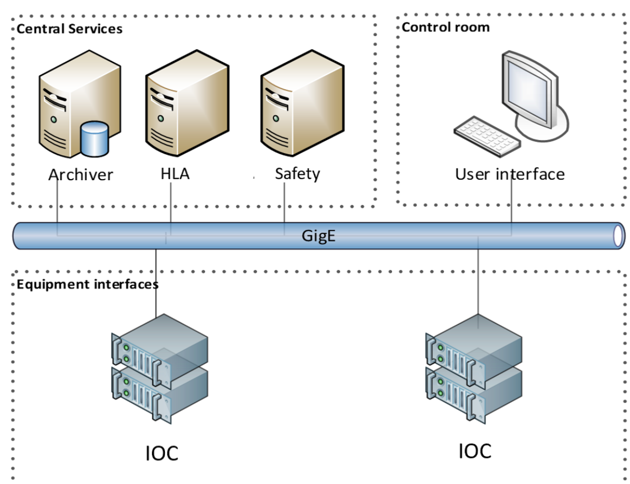

Figure 1: EPICS framework for the TEX Control System.

RESOURCE TIER

Currently we proceed in the integration of all the hardware equipment present at TEX. IOCs and support modules for any family of device have developed or acquired from repositories, as shown in Table 1.

CS hardware is composed of a standardised hardware platform, components, development tools and services. Interfaces with the equipment and parts of the facility are made through a set of analog and digital signals, real-time control loops and other communication buses.

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Table 1: CS Device Families

Device Family
ScandiNova [6] RF Modulator
LiberaLLRF
Microwave Amps. [7] RF Driver
Pfeiffer Vacuum Gauges
Agilent Vacuum Ion-Pumps
Timing System
RTD sensors
SMC Chiller
Fluid Plant PLC
Faraday Cups
Backhoff Motors
Basler Camera
Magnets
Machine Protection System
Personnel Safety System

SERVICES TIER

Inside the Services tier we deployed all the tools required to assist the operation of the facility and the minimal data processing. The computers of the data and services tier will offer high CPU performance and reliability, and will have access to substantial storage capacities. The computers of the resource tier will have a wide assortment of input/output capabilities, reflecting the need for control system communicate with a wide array of equipment.

Functional Safety

Safety life-cycle assessment based on statistical methods for risk reduction, Fig. 2, through the estimation of the mean time between failure (MTBF), system reliability and availability and compliance with:

- IEC-61508 standard on "Functional Safety"
- NCRP reports 88 on "Radiation Alarms and Access Control Systems"
- ANSI reports 43.1 on "Radiation Safety for the Design and Operation of Particle Accelerator"

For these reason we developed Personnel Safety System (PSS) and Machine Protection System (MPS) through FPGA-based devices [8, 9] to provide hard-wired, fast and reliable protection to TEX.
Systems capabilities:

- Real-Time intervention (with rep. rate up to 10 kHz)
- Dual Modular Redundancy
- Scalable and distributed design
- Fail-safe and fool-proof design

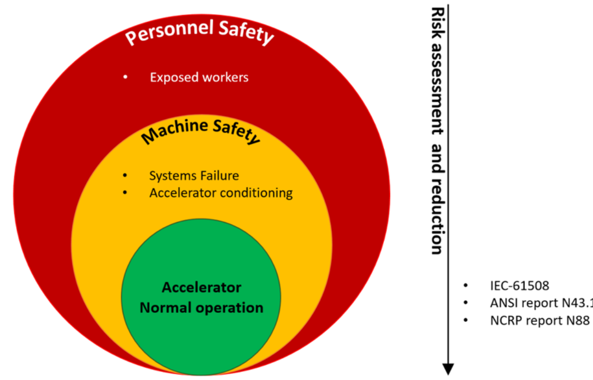

Figure 2: Risk assessment for the risk reduction methodology first for protection personnel then for the machine equipment.

Archiver

We deployed an instance of EPICS Archiver Appliance from SLAC [10] to handle the data storage of the facility. Thanks to native capability of multiple stages, Fig. 3, and an inbuilt process to move data between the stages, we designed the data policy according with the scheme:

- Ramdisk for the short term store - in this storage stage, we store data at a granularity of an hour.
- SSD drives for the medium term store - in this storage stage, we store data at a granularity of a day.
- A SAN for the long term store - in this storage stage, we store data at a granularity of a month. This stage is physically located at CNAF data center, the INFN European Open Science Cloud (EOSC) pillar of the INFN.

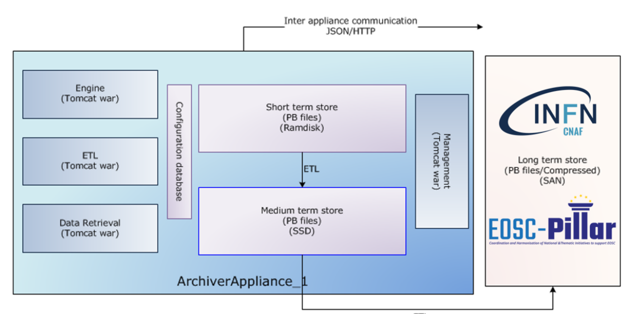

Figure 3: EPICS Archiver Appliance workflow and storage stages.

Autonomous Operation

All the conditioning procedure is completely automatic [9] through integrated algorithm in the middle-layer of the control system. Such tool is mainly capable of:

- Increase the RF feedback set level following a sigmoid curve.

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- Detect generic modulator ilks.
- Handle breakdown (BD) events from:
  - Modulator RF Digitizer
  - LLRF
  - vacuum gauges
  - ML-based vacuum anomaly detection
  - ML-based BD real-time detection from RF signals
- Handle mean vacuum level rising trends
- After a breakdown, it makes a step down, decreasing the power and turns on RF after vacuum restoring.
- Identify and handle clusters of BDs.

PRESENTATION TIER

About User Interfaces (UI) we involved, Table 2, reliable state-of-art graphic interfaces tool to simplify maintenance and improve user experience, Fig. 4 and 5, for TEX operators and users.

Table 2: Presentation Tier interfaces

Interface	Solution
Engineering consoles	LabView
Archive Viewer	Grafana [11]
Archiver Data Retrieval	web-based UI
Logbook	ELog
Reference Manual	Confluence
Alarm Notification	Telegram [12]

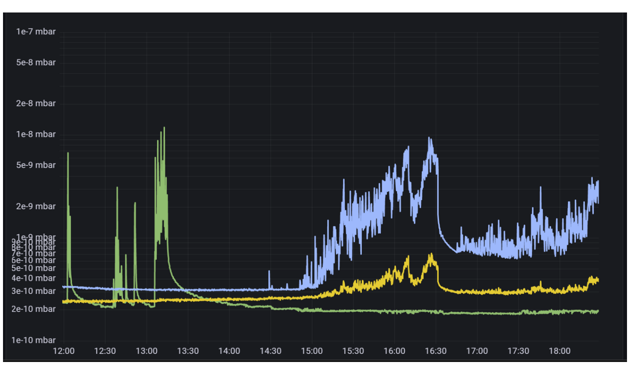

Figure 4: Klystron historical data viewer from Grafana.

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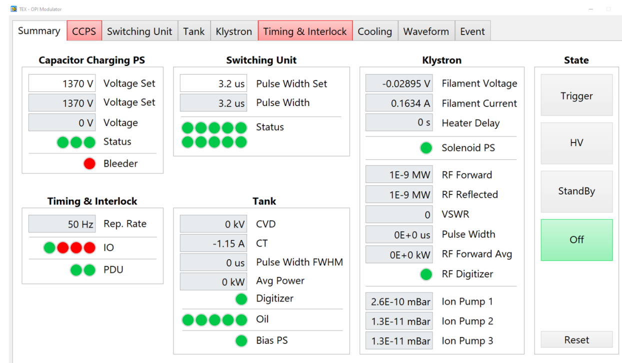

Figure 5: RF Modulator interfaces.

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