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MaRIE INJECTOR TEST-STAND INSTRUMENTATION & CONTROL SYSTEM CONCEPTUAL DESIGN*

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Abstract

Los Alamos National Laboratory (LANL) has defined a flagship science facility Matter-Radiation Interactions in Extremes (MaRIE) (~$1.3B for full capabilities) that builds on the existing Los Alamos Neutron Science Center (LANSCE) facility to provide unique experimental tools to develop next-generation materials that will perform predictably and on demand for currently unattainable lifetimes in extreme environments. At its core a 42 keV XFEL will be coupled with the MW class proton accelerator at LANSCE.

While the larger MaRIE project is working on a pre-conceptual design, a smaller LANL team is working on an injector test stand to be constructed at LANL in the course of preparation for MaRIE. The test stand will consist of a photo injector and an initial accelerating section with a bunch compression section. The goal of this facility will be to carry out studies that will validate and determine optimal design parameters for the prototype injector, and to facilitate a direct demonstration of the required beam characteristics for MaRIE.

This paper will give a brief overview of the proposed MaRIE facility and present the conceptual design for the injector test stand with the focus on timing, instrumentation and control system.

INTRODUCTION

MaRIE Facility Overview

MaRIE (Matter-Radiation Interactions in Extremes) is designed to understand the condition of certain materials. When combined with the emerging computational capability to simulate materials at ultrahigh resolution, MaRIE will fill the gap in understanding of micro- and mesoscale materials phenomena and how they affect performance of those materials. MaRIE will specifically bring two major new capabilities (a) the ability to predict how micro- and mesoscale materials properties evolve under extreme conditions (including aging) and impact performance, and (b) the ability to predict the microstructure of new materials (or those resulting from new manufacturing processes) and how that will affect material performances [1].

Leveraging LANSCE's existing 1 MW, 0.8 GeV proton accelerator, MaRIE will provide [1]:

- The world's first very hard (42 keV) XFEL;
- A new Multi-Probe Diagnostic Hall (MPDH), coupling hard, coherent, brilliant x-ray photons with 12 GeV electron and 0.8 GeV proton radiographic tools in dynamic extremes; and,
- A unique Making, Measuring, and Modeling Materials (M4) facility for materials synthesis and characterization with collocated high-performance computational co-design and data visualization tools focused on the mesoscale.

MaRIE Injector Test Stand Overview

Every successful high energy accelerator facility built to date has demonstrated the need to have an in-house group of experts intimately familiar with the construction and operation of the integrated operation of a representative accelerator system. The MaRIE Injector Test Stand (MITS) will meet this need and provide additional advantages as detailed below [2]:

MITS will be built to accommodate more design flexibility and be more heavily instrumented than the final system installed in the MaRIE XFEL accelerator. The reason being the accelerator test stand is primarily an initial prototype for the front end of the MaRIE XFEL accelerator. Results from the studies on MITS will include performance improvements and a potentially simplified design to give the final MaRIE version greater reliability and improve the ease of operations and maintenance.

MITS will incorporate most of the major systems relevant to building a 12 GeV linac - the major cost component of the XFEL. Thus, construction and operation of the test stand significantly reduces the required cost and schedule contingency in preparation for preliminary design, thereby potentially reducing overall MaRIE project cost and substantially reducing risk.

Although MITS only goes to 265 MeV, the remaining linac sections and beam line components required to go to 12 GeV are expected to be duplicates of the test stand linac section that follows the photo injector section, with similar RF systems, beam line components, bunch compressors, timing, diagnostics, instrumentation, and controls.

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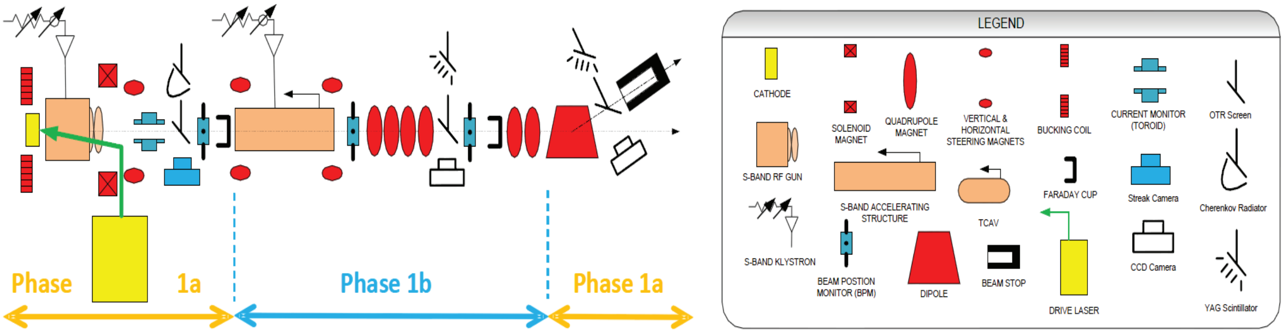

Figure 1: MaRIE Injector Test Stand (MITS) beam line layout showing Phase 1a and Phase 1b (being inserted).

Following the current design plan, MITS will be constructed in two phases. Phase 1a will be the AFEL L-band injector [3] operating at 20 MeV. Phase 1b inserts an S-band accelerating structure (f_{rf} = 2.856 GHz) between the RF gun and the beam stop. This will take the energy up to 265 MeV. The layout for both phases is shown in Fig. 1.

MaRIE INJECTOR TEST STAND CONTROL SYSTEM

The controls system for the MITS provides control, monitoring, operation, and diagnostics. Controls provides all the data acquisition and controls hardware, software, networking, back-office computing facility, access control, and the MITS control room facility. The system scope and architecture spans from low-level interface and control of injector and beam line components to high level automation.

Based on the local expertise and vested control system developments, the injector and beam line devices will be interfaced directly to EPICS (Experimental Physics and Industrial Control System) Input/ Output Controller (IOC) front-ends employing VME and, National Instruments cRIO form factors, or indirectly to EPICS via Programmable Logic Controllers (PLCs). EPICS Channel Access over Ethernet provides the communication front-end computers and mid- and upper-level control system elements. EPICS “soft IOCs” processes running on servers perform important control function, which require no direct hardware I/O.

Overall Controls System Requirements

The technical requirements are determine by which subsystem the control system will interface to. Furthermore, there is a need for back-office servers that provide archiving and file management services.

The functional requirements include the need of operational control of MITS devices including all diagnostic instrumentation in the MITS Control Room (MCR). Necessary data for monitoring and control of MITS need to be available in MCR and for retrieval during and after the commissioning and testing phase for analysis purposes.

Timing System Requirements

Short Pulse Objective:

- Measure beam emittance of MITS at 265 MeV with a 1.5 µs RF traveling wave pulse length, at 60 Hz
- Use two laser pulses with variable spacing ranging from 350 ps minimum to about 50 ns maximum.
- Test two pulses conditions:
  - 2 nC pulse followed by a 0.1 nC pulse
  - 0.1 nC pulse followed by a 0.1 nC pulse

Long Pulse Objective:

- Measure the probability of a breakdown in the S-band structure with a pulse length of up to 10 µs with an accelerating gradient of ~25 MV/m. (No electron beam needed – the RF repetition rate can be reduced from 60 Hz to 10 Hz)

Furthermore, the timing system is responsible for the synchronized operation of MITS. It needs to provide a common set of triggers for the pulsed operation of hardware that generates the beam and for the devices that measure the beam. At the same time it needs to provide a digital time stamp to the control system so that every pulse in the MITS can be uniquely identified.

The synchronization aspect of the timing system relates to both the RF system and the AC power distribution. The RF synchronization ensures that the timing triggers are synchronized to the rising or falling edge of the LLRF phase reference signal that drives the MITS klystrons. At a coarser level the triggers are also synchronized to the 60 Hz AC site utility power distribution.

The timing control system, must allow beam event timing pattern definitions that will allow all diagnostic devices on MITS to acquire data on the same pulse so that different parameters such as beam position, beam energy and so on can be correlated on a single pulse. The timing control system must also buffer this data at the full 60 Hz beam rate so that pulse-to-pulse jitter of all these parameters can be quantified. The timing system specifications are summarized in Table 1.

Table 1: Timing System Specifications

Parameter	Value	Unit
Max beam trigger & timing event rate	60	Hz
RF synchronization frequency	1.428	MHz
AC power synchronization frequency	60	Hz
Pulse to Pulse trigger stability (rms)	<20	ps
Standard trigger delay resolution	8.4	µs
Optional fine vernier (÷20) trigger delay resolution	420	ps
Long term stability	20	ps
Selectable beam rates	1-60	Hz

Given recent developments, the timing system should use the event based timing system designed for the LANSCE Risk-Mitigation upgrade project [4].

MITS CONTROL SYSTEM DESIGN

Overall Control System Design

Similar to the LANSCE user facility the controls design will be based on three layer client-server architecture. Low-level control, monitoring and diagnostics are performed by EPICS IOCs that control beam line devices and diagnostic systems, and serve up data via the EPICS Channel Access network.

Mid-layer processes such as feedback and machine protection are performed by specialized IOCs that are both clients of the low-level IOCs, and data servers to high level processes.

Client processes are performed by applications and databases executed on Linux servers and operator consoles in the control room.

MITS requirements for instrumentation and control are largely the same as for the LANSCE user facility, so the design is in many cases a copy of existing systems. In some cases improvements in design or technology will be implemented based on (1) change in requirements, (2) improving reliability, (3) increasing the level of standardization and maintainability of the systems (e.g. aligning the systems with any new industry standards), (4) reducing costs either in the development or implementation phases, and (5) taking advantage of COTS (Commercial Off The Shelf) hardware.

Timing System Design

The timing system is a complex entity consisting of many components. These components include RF signal transmission, reception and processing for distributing the timing signal and dedicated computer systems that set up and coordinate the delay and initiation of the system's timed triggers. The timing system design is based on the mature LANSCE Risk Mitigation system design using COTS components [5]. These are largely supplied by Micro-Research Finland.

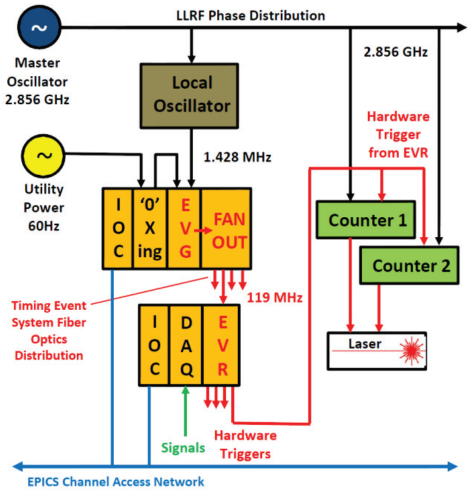

Figure 2: Timing System High Level Design.

The design shown in Fig. 2 provides pulse by pulse coordination that triggers beam control and data acquisition (DAQ), synchronized with the 119 MHz timing event clock and the 60 Hz AC utility power line phase.

The Event Generator (EVG) will broadcast over a dedicated fiber optics network to MITS devices and systems, sharing the same master oscillator. The current EVG module fulfils the MITS requirements – producing programmable beam rate triggers up to 60 Hz and with a long term jitter less than 20 ps for broadcasting at 60 Hz over a 2.5 GB/s optical serial link to the Event Receivers (EVRs) [6].

The 8 bit events broadcast by the EVG over the fiber optics Event Links (125 MHz max) are received by an EVR that is built into an EPICS IOC that requires timing system information. The EVR translates the timing event into hardware timing signals and software events codes with a delay resolution of 8.4 ns (1/119 MHz).

The design employs two counters capable of 2.856 GHz frequency measurements therefore providing a 350 ps time resolution of up to 50 ns maximum within MITS 15 µs macropulse. In order to position the pulse within the marcopulse the event generator will give the counters the information of when to start counting.

In order to characterize the pulse to pulse stability of MITS the timing system requirements include the ability to record the data from every pulsed device on the same event pulse. The data from synchronized pulses will be written to buffers at 60 Hz. The EVRs write to a software application on the IOC to initiate and capture the beam synchronized acquisition data, which will be used by higher-level applications for analysis and beam tuning.

The maximum beam trigger rate is 60 Hz the Long Pulse objective asked for 10 Hz operations.

FUTURE

The MaRIE project is hopeful to achieve United States - Department of Energy's Critical Decision - 0 milestone in the spring of 2015.

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