HIGH-SPEED DATA ACQUISITION OF SENSOR SIGNALS FOR PHYSICAL MODEL VERIFICATION AT CERN HIRADMAT (SHC-DAQ)

C. Charrondière, M. Guinchard, S.D. Marques Dos Santos, CERN, Geneva, Switzerland

Abstract

A high-speed data acquisition system was successfully developed and put into production with the sensors in a harsh radiation environment in a couple of months to test new materials impacted by proton beams for future use in beam intercepting devices. A 4 MHz ADC with high impedance and low capacitance was used to digitize the data at a 2 MHz bandwidth. The system requirements were to design a full speed data streaming on a trigger during up to 30 ms and then reconfigure the hardware in less than 500 ms to perform a 100 Hz acquisition for 30 seconds. Experimental data were acquired, using LabVIEW real-time, relying on extensive embedded instrumentation (strain gauges and temperature sensors) and on acquisition boards hosted on a PXI crate. The data acquisition system has a dynamic range and sampling rate that are sufficient to acquire the very fast and intense shock waves generated by the beam impact. This presentation covers the requirements, the design, development and commissioning of the system. The overall performance, user experience and preliminary results are reported.

INTRODUCTION

The introduction in recent years of new, extremely energetic particle accelerators such as the LHC [1] has required the development of advanced methods to predict the behaviour of beam intercepting devices (BID) [2] in case of direct beam impact.

Complex numerical methods have been used for several years to study the dynamic phenomena, generated in matter when beams made of highly energetic particles impact it. Unfortunately, the material models required to perform such simulations, at the extreme conditions, as to temperature, pressure and density, induced by such impacts, are hardly available in scientific literature. Finally, very little data can be found for non-conventional alloys and compounds.

In order to probe and evaluate such models, a first-of-its-kind experiment was recently carried out at CERN HiRadMat (HRMT) facility [3], entailing the controlled impact of intense proton pulses on specimens made of six different materials for BID. For a comprehensive characterization, experimental data were acquired relying on embedded instrumentation (strain gauges, temperature probes and vacuum sensors) and on remote-acquisition devices. To be able to handle the large amount of data with high accuracy a data acquisition (DAQ) system based on PXI platform has been developed running a LabVIEW dedicated software.

HRMT-14 LAYOUT AND INSTRUMENTATION

In order to gather experimental data for a comprehensive characterization of relevant materials, a specific test (HRMT-14) was performed in October 2012 in the HiRadMat facility [4]. The experimental setup consisted of a multi-material [5] sample holder allowing testing specimens of six different materials under proton beams of different intensity, at the energy of 440 GeV.

General Assembly

The material sample holder was constituted by a vacuum vessel and a specimen housing featuring 12 sample tiers arranged in two arrays of six (Fig. 1).

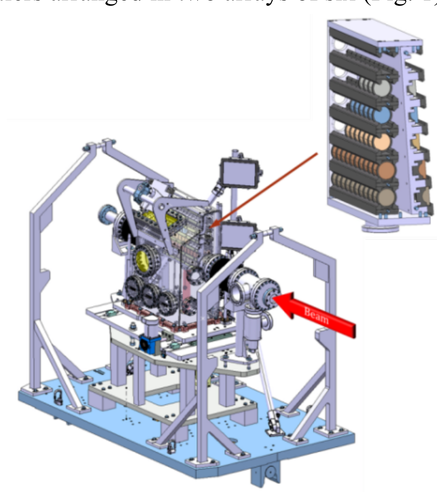

Figure 1: General assembly of the HRMT-14 test-bench.

Instrumentation

The test bench was designed and equipped to measure in real time physical quantities necessary to reconstruct the material behaviour, such as axial and hoop strains, radial velocity and temperature as shown in Table1.

Table 1: DAQ Characteristic

Sensor type	Quantity	Sampling frequency
Strain gauges	244	4 MHz
Vibrometer	2	5 MHz
PT100	36	100 Hz
Pirani gauge	1	100 Hz

Data was collected at very high sampling rates to fit expected shock wave profiles with sufficient accuracy.

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DATA ACQUISITION SYSTEM

Due to limitations to the number of available cables in the HiRadMat facility, a radiation-hard multiplexing hardware was developed (8:1 In/Out ratio) and installed on the test-bench. Multiplexer control was transferred to the surface control room, since underground facilities were not accessible during the experiment.

Data Acquisition System Requirements

The main requirements of the data acquisition system are listed below:

- 48 channels at 5 MHz sampling frequency
- 9 channels at 100 Hz for temperature sensors
- 10 channels at 100 Hz for voltages status.
- High impedance
- Differential measurements
- All signals synchronized down to 10ns
- High availability of the system
- Acquisition on trigger
- Fast channels recorded up to 100ms
- Slow channels recorded up to 30s

Choosing the Right System

The aim of the acquisition system is to record data from a vibrometer and strain gauges with a bandwidth of up to 2.5MHz. The system requires a data acquisition board with a frequency up to 5MS/s. Two options have been studied. The first option was to buy a complete off the shelf system, hardware and software. The second option was to buy the hardware from National Instrument and write the software in house using LabVIEW. The off the shelf system would be the best in terms of data acquisition bandwidth and signal to noise ratio. The flexibility and the big difference of budget made it clear that the system should be designed using PXI and LabVIEW even if the schedule was extremely tight (Table 2).

Table 2: Schedule

Project study	March 2012
Purchase DAQ hardware	June 2012
First Measurement	July 2012
Real Measurements	September 2012

Choosing the Hardware and the Architecture

The system is built using a PXI express chassis (PXIe-1075) with a PXI express controller (PXIe-8115) running LabVIEW Real-Time on PharLap operating system, to address the deterministic requirement of such an application. 12 data acquisition cards (PXIe-6124), each having 4 simultaneously sampled analog inputs at 4MS/s per channel with 16 bit resolution; although this is lower than specified, it is still in an acceptable range. A card to monitor the temperature was also added (PXIe-4357); it can record up to 20 PT100 channels at 100S/s/ch maximum. Another card to monitor different voltages from power supplies (PXI-6289) was also added. A remote computer, referred as "Host computer", is used to configure the real time system and receive the data online. As a safety system, a remote reset is added to be able to power cycle the entire chassis in case of major issue. (Fig. 2).

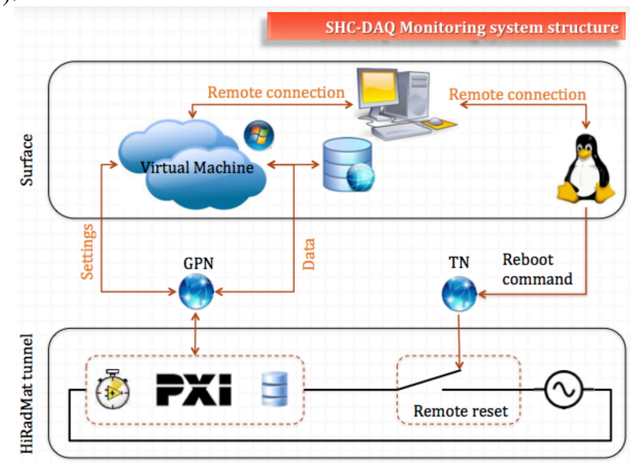

Figure 2: Data acquisition architecture.

Configuring the Hardware

Looking at the simulation, the system has to record data from the strain gauges and vibrometer at the maximum speed during around 100ms. Then the acquisition frequency is lowered to 100Hz to study the thermal effect and the propagation over 30seconds. The system also has to record voltages from power supply and temperature at 100Hz over the 30seconds.

When the beam enters the samples, the data acquisition system is triggerred. The TTL trigger signal has a jitter of ±1ms. For this reason, the fast acquisition is performed using a pre-trigger of at least 1ms to avoid losing data. The slow acquisition (i.e. 100Hz) can start directly after the trigger. In a post-triggered acquisition, the hardware starts the A/D conversions after the trigger is received. The trigger signal in this case is referred to as the "start trigger". In a pre-triggered acquisition, the hardware starts acquiring data before the trigger signal is received. With this type of acquisition, the user can view the signal before the trigger event. In such applications, the hardware initiates data acquisition and stores the data in a circular buffer in the card's memory. The buffer is large enough to ensure that the required number of pre-trigger samples is stored. The primary responsibility of trigger mechanism is to stop the acquisition so that the samples left in memory represent the "slice-in-time" the user wants. The trigger signal in this case is referred to as the "reference trigger".

Software Structure

The software structure running on the real time target is made using 3 parallel loops. (Fig. 3) The first loop is dedicated to the communication with the Host computer. The communication is handled over the network using Shared Variables from National Instruments. The configuration can be viewed on the Host computer,

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changed and sent to the target. The configuration actually used on the PXI is then sent back from the real time environment to the host. As soon as a new configuration is received by the PXI, the second loop, assigned to the hardware access, is activated. The configuration is applied on the 3 card types in parallel. The 12 PXIe-6124 cards, dedicated to strain gauges and vibrometer, are armed using the "reference trigger" method to allow visualising a couple of milliseconds before the trigger. The PXIe-4357 and PXI-6289, dedicated respectively to PT100 and voltages, are armed in 2 parallel tasks using the "start trigger" method. When the trigger is received, data are pushed to the third loop, dedicated to data handling. About 500MB of data have to be streamed to disk as fast as possible to allow the next bunch of data to be stored. The Technical Data Management Streaming (TDMS) [6] file format from National Instruments has been chosen for its high-speed and file size. The data are saved locally on the hard disk of the PXI system and published on the network using Shared Variables. Thus the Host computer receives the data shortly after the trigger.

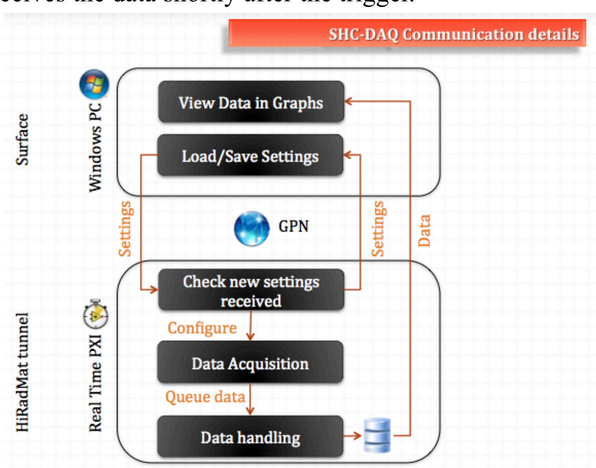

Figure 3: Communication structure.

As soon as the PXIe-6124 running at 4MS/s using "reference trigger" has finished its task, the cards have to be reconfigured to record data at 100Hz for 30seconds. This reconfiguration of the hardware results in a dead band where no data will be acquired using these cards. This time can be up to 1 second long. (Fig. 4)

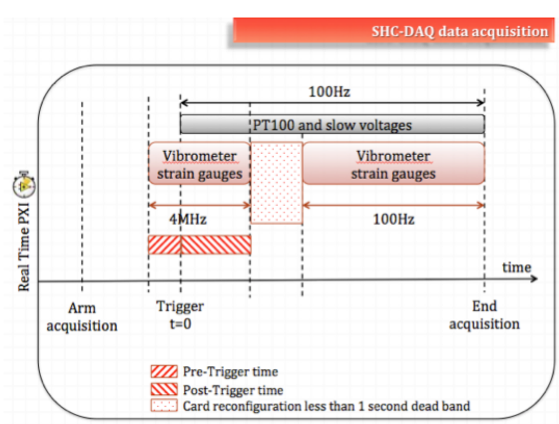

Figure 4: Data acquisition timing.

The data are stored locally on the PXI controller's disk. The users can FTP the data to their computer for offline analysis. During this time the data acquisition system is automatically reconfigured waiting for another trigger. The user can still change the configuration if needed. The system will be automatically paused and re-armed with the new settings.

PRELIMINARY RESULTS

A very large amount of data was acquired during the experiment and is currently processed and analysed. Experimental measurements and numerical simulations were compared. Differences in measured values are probably mainly due to the noise on cables and gauges during the acquisition as well as to errors on the beam impacting position. Preliminary [7] measurements well match results of advanced computations, giving promising indications on the validity of the constitutive models used for this material.

CONCLUSIONS

During the entire tests the application never failed to trigger and save the data. On a single occasion the remote reset had to be used. This was when the real time system was not reacting to any command. In this particular case, as the system restarted very easily following the power cycle, a single event upset from radiation to the electronics is suspected,.

A large amount of data is being treated and will hopefully help deriving constitutive models for presently the less known composite materials.

REFERENCES

[1] The LHC Design Report, http://ab-div.web.cern.ch/ab-div/Publications/LHC-DesignReport.html, July 2004.
[2] R. Assmann et al. "Requirements for LHC Collimation System", EPAC'02, Paris, June 2002.
[3] I. Efthymiopoulos et al., "HiRadMat: a New Irradiation Facility for Material Testing at CERN", IPAC'11, San Sebastián, September 2011.
[4] C. Hessler et al. "Results from the HIRADMAT primary beam line commissioning", IPAC'11, San Sebastián, September 2011.
[5] A. Bertarelli et al., "Research and Development of Novel Advanced Materials for Next-generation Collimators", IPAC'11, San Sebastián, September 2011.
[6] The NI TDMS file format, http://www.ni.com/white-paper/3727/en/, July 2012.
[7] A. Bertarelli et al., "Preliminary results of an experiment on advanced collimator materials at CERN HIRADMAT facility", IPAC'13, Shangai China, May 2013.

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