OVERVIEW OF LINAC4 BEAM INSTRUMENTATION SOFTWARE

L. K. Jensen, M. Andersen, A. Guerrero, B. Kolad, M. Ludwig, U. Raich, F. Roncarolo
Geneva, Switzerland

Abstract

This paper presents an overview of results from the recent Linac4 commissioning with H⁻ beam at CERN. It covers beam instrumentation systems acquiring beam intensity, position, transverse and longitudinal profile and transverse emittance [1].

INTRODUCTION

As a first step in CERN's upgrade of its injector chain for the LHC, a 160 MeV H^- Linac (Linac4) will be built, injecting protons into the PS Booster (Figure 1) after an electron-stripping system made of foils.

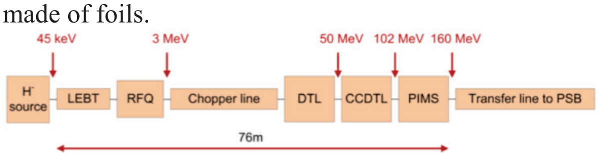

Figure 1: Overview of the Linac4 project from the H^- source up the PSB injection transfer-line.

The low energy part consisting of the source itself, a Radio-Frequency Quadrupole (RFQ) [2] and a chopper line needed special care. A 3 MeV test stand was therefore set up with a dedicated measurement bench (Figure 2) allowing characterising the beam. The installation of several beam instrumentation systems [3] did not only serve for operational users but also for BE/BI to verify the correct functioning of systems being developed for use in other operational facilities after long-shutdown 1 (LS1).

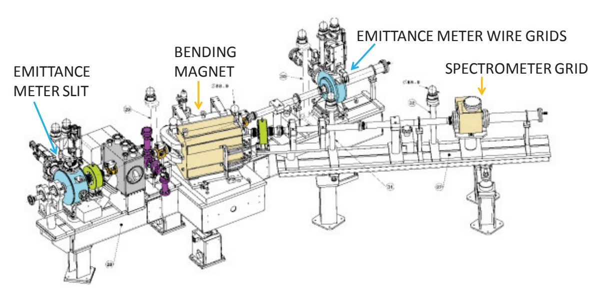

Figure 2: Schematic showing the measurement bench.

The BI Group is making serious efforts to standardise electronics and software basing them on known and supported technology at CERN. The Linac4 project is no exception to the rule; in several of the systems presented in this paper a CERN developed multi-channel ADC module is used to acquire the analogue signals for wire-grids and wire-scanners allowing reusing low-level electronics and access libraries. In several cases, Siemens PLCs are used to control movement (IN/OUT and stepping motors) and here also a general standardisation using the FESA to iePLC [4] protocol is employed.

BEAM INTENSITY MONITORS INCLUDING WATCH-DOG

To measure the beam intensity in Linac4 and its transfer-lines at low energy, five beam current transformers (BCTs) are employed. For Linac4 as in most transfer-lines at CERN, a digital acquisition module called the "TRIC" is employed [5]. Rather than a simple ADC module with subsequent software integration, the on-board FPGA implements several integration gates for beam and calibration signal as well as DC offsets through user-defined time windows. Calibrated values for the beam intensity are provided by the BCTTRIC FESA class whose software is designed to work in a sequence of actions:

1. Preparation of the hardware acquisition module by setting up integration parameters
2. An external timing trigger starts the ADC sampling to be synchronous to the beginning of the beam pulse
3. The data acquired are extracted from the TRIC module after the beam has passed and performs post-processing of the data, producing intensity normalised as number of charges and current

A Java-based Expert GUI program was developed to facilitate the setting-up allowing experienced beam commissioning specialists to choose appropriate acquisition intervals, while at the same time observing the acquired intensity data (see Figure 3 below for an example showing results with the actual Linac4 beam pulse).

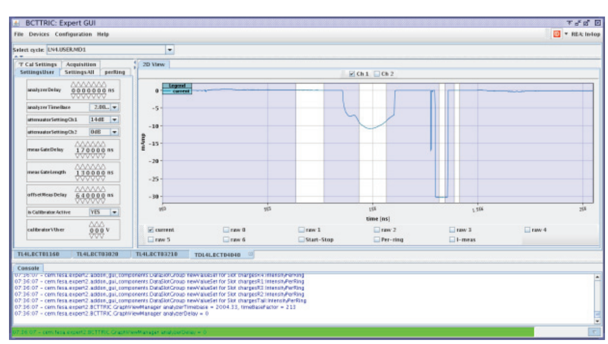

Figure 3: Java GUI allowing direct observation of beam intensity signals and the integration gates. The horizontal scale is in ns while the vertical scale is in mA.

In Linac4 as is the case in Linac2, BCTs are used for a software-based intensity watch-dog whose specification

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can be found in [6]. The interlocking principle for Linac4 is based on comparing intensity values between two detectors.

The interlock is implemented in a separate FESA class named BCTWD with a set of real-time actions triggered before and after the beam pulse. Inter-Process Communication (IPC) structures are used to transmit beam intensity values as well as time-stamps from the BCTTRIC to the BCTWD classes (for details see [7]) both running on the same front-end. Despite the limited number of measurement devices available so far, the watch-dog functionality was seen to be working correctly providing confidence for the future running.

BEAM POSITION MONITORS

The Linac4 Beam Position Measurement (BPM) relies on readout of commercial ADC electronics (SIS3302) connected to the pick-ups via dedicated electronics developed at CERN [8]. Each pick-up provides four electrode signals (h+, h-, v+ and v-) modulated on a fixed carrier frequency (F_{int}). A derived ADC clock of $4xF_{int}$ allows defining and decoding I/Q-quadruplets into magnitudes and relative phases, from which horizontal and vertical positions, beam intensity and common phases are computed as primary observables. Since the decoding is done in software, this results in simpler electronics layouts and additional flexibility. It clearly also means more complex software that require thorough testing, something which has not been possible yet. Combining a pair of pickups, the momentum and energy can be derived as secondary observables by calculating the time-of-flight. Adding the signals from all four electrodes the beam intensity can be measured when cross-calibrating the BPM with a nearby BCT. This system was tested with beam in the Linac2-PSB line and later in the 3MeV test stand for Linac4 providing encouraging results as can be seen in Fig. 4 below.

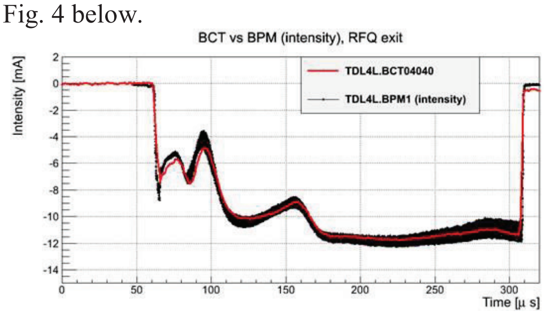

Figure 4: cross-calibrated intensity signal comparing signals from a BPM and a nearby BCT.

WIRE GRIDS AND SPECTROMETER

The Linac4 wire-grid front-end software is like the BCT and BPM systems developed using the FESA framework combining several generic classes to produce a dedicated instrument. In total three FESA classes were used, two of them for slow control (IN/OUT and gain control) and one acquiring the SEM-grid data, acting as a unique interface towards operational applications. The above class-split comes from the wide variety of hardware (RS422, VMOD-TTL and PLC) used to control the wire-grid devices allowing additional flexibility and code re-use. During LS1, the complete wire-grid electronics and software systems will be renovated with the majority based on commercial RS422 electronics designed and built at CERN. Some more complex devices will however remain under PLC typically to avoid collisions between detectors situated in the same mechanical assembly.

The 3rd software class acting as interface to operational applications deals with the slow control servers just described however its main task is performing the wire-grid acquisition synchronized with machine timing events. Each wire-grid is a separate device seen from the control system and full hardware configuration is defined for its IN/OUT and gain handling, while combining the characteristics of each device (e.g. number of ADC's used per device, mapping of channels, number of planes…) and provide a different data interface for the hardware expert or operational user. A VME-based 36 channel ADC module acquires the wire signal at up to 250 KHz providing several points along the Linac4 beam-pulse. An example of a single profile acquired can be seen in Fig. 5 below.

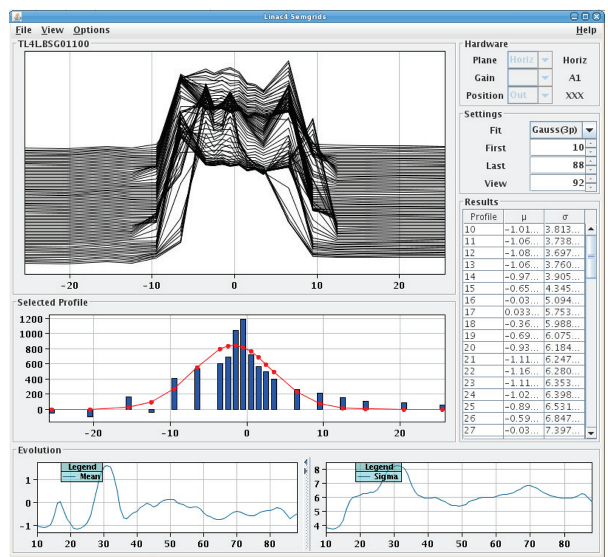

Figure 5: Transverse profiles measured with a Linac4 wire-grid. In the upper plot, the horizontal axis shows the position of the wires on the grid and the vertical axis shows the relative amplitude of the different acquired channels (some show hardware issues as can be seen more clearly in the middle plot).

WIRE-SCANNERS

Two wire scanners are installed in the chopper line consisting of two isolated carbon wires forming a cross. The wires traverse the beam at 45° thereby measuring horizontal and vertical beam profiles at the same time. The wire movement is synchronized with the beam pulse being repeated every 1.2 seconds. An ADC

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module similar to that used for the wire grids is used for readout providing a time resolution of 4 µs. This feature was particularly interesting when the chopper was switched on and the profiles of displaced chopped and un-chopped beam could be observed, results from which can be seen in Fig. 6 below.

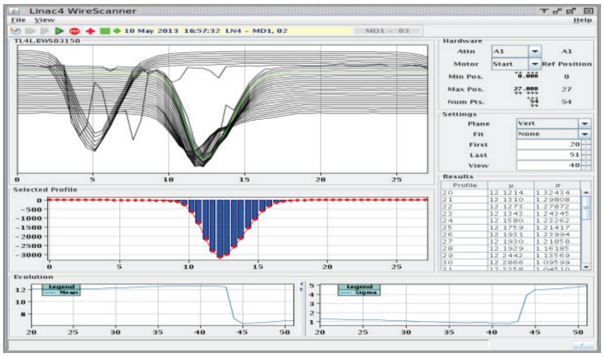

Figure 6: Profiles from the wire scanner while chopping which can be seen from the two distinct negative peaks in the distribution shown on the top.

EMITTANCE METERS

Transverse emittance is measured through a phase space scan with a slit/grid emittance meter. Separate slits and grids for the horizontal and vertical phase space planes can be moved individually with stepping motors providing 50 µm positioning precision. The emittance meter uses the same ADC modules as the wire grids and the emittance can therefore be measured along the beam pulse with a time resolution on 4 µs. The device consists of four moving parts, two grids and two slits (for vertical and horizontal axis respectively). A FESA server allows controlling the movement of these (via a PLC module which implements a hardware interlock to prevent collisions). Functionality for basic data analysis is also provided: it is possible to plot raw ADC signal for selected wires. Emittance is calculated by acquiring beam profiles for different positions of slit and grid with the main analysis done by high-level LabView software. Fig. 7 below shows an example of the profiles acquired and the results following extensive data analysis.

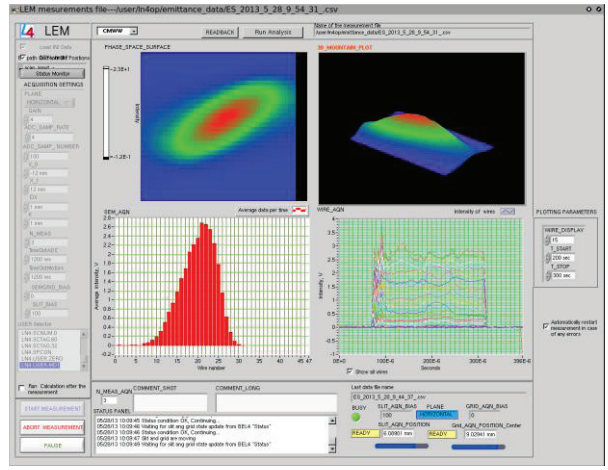

Figure 7: Transverse emittance-meter LabView application showing the emittance-meter results from 2D images to the projections.

BUNCH-SHAPE MONITOR (BSM)

The BSM allows measuring the longitudinal distribution of the beam. It is based on a wire with a high negative potential, which is inserted into the beam. Electrons are created through secondary emission and accelerated through an electric field from the wire. The wire movement into the beam is implemented through a stepping motor controlled by a PLC. The remaining electronics is controlled through a rack-mount PC with DAC and ADC modules controlled by LabView programs. Figure 8 below shows an example of results obtained.

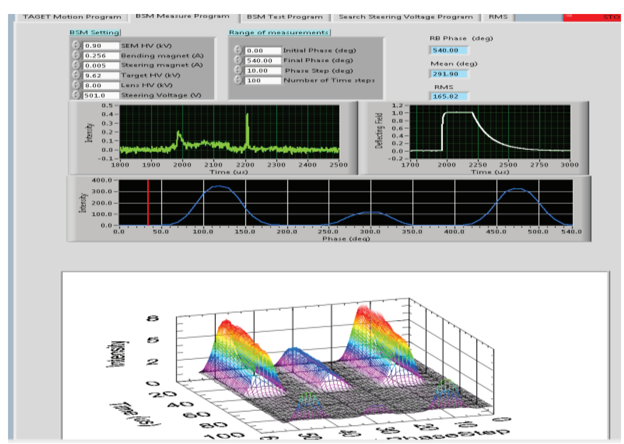

Figure 8: Bunch Shape Monitor LabView application. The lower plot shows the longitudinal beam distribution along the batch.

Ideas for extending the use of the BSM monitor to measure the beam emittance in the Linac4->PSB transfer-line means that work needs to be undertaken to fully integrate the BSM on the control-system. It is presently foreseen to replace the PC system with standard electronics components from the BE/CO tool-box. Software efforts (low-level and high-level) will

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then be required before the installation and commissioning in the machine.

ACKNOWLEDGMENT

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CONCLUSION AND OUTLOOK

At the 3 MeV test-stand the hardware and software of many devices to be employed in Linac-4 and its transfer lines were commissioned allowing the first functionality tests to be made. The source, RFQ, chopper line and the temporary measurement bench are now being installed in their final positions in the Linac4 tunnel and here measurements will be repeated and improved before the subsequent parts of the Linac (DTL, CCDTL and PIMS) with their corresponding beam diagnostic devices will be installed. The BE/BI software efforts which includes a more definitive controls integration of the BSM instrument will continue at least until end of 2016 as it is also foreseen to test the ion to proton stripping systems. It is presently foreseen to connect Linac4 to the PSB during the 2nd long-shut down now scheduled to take place during 2018.

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