BEAM POSITION AND PHASE MONITORS FOR THE LANSCE LINAC*

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Abstract

New beam-position and phase monitors are under development for the linac at the Los Alamos Neutron Science Center (LANSCE.) Transducers have been designed and are being installed. We are considering many options for the electronic instrumentation to process the signals and provide position and phase data with the necessary precision and flexibility to serve the various required functions. We'll present the various options under consideration for instrumentation along with the advantages and shortcomings of these options.

INTRODUCTION

The LANSCE linac has been without functional beam position monitors (BPMs) for most of its 40-year existence. While transducers were installed during the initial construction, satisfactory data were never available due to problems with the signal processing electronics. Beam phase measurements have been very successful and are relied upon for tune-up of the linac and for troubleshooting, but the phase measurements are not reliable for production beams due to their time structures.

A program is currently underway to provide the capability for beam position measurements and to improve the beam phase measurements. Given the problems with the feed-throughs on the original BPM transducers, a new design has been developed.

Various schemes for processing the signals and serving data are under consideration. The linac delivers beams of two different species to five experimental areas with each requiring a unique pulse structure; this is the major challenge for the system.

The various beam pulse formats are described in the next section. In the following sections the schemes for data acquisition are described along with their strengths and weaknesses.

BEAM TIME STRUCTURES

The LANSCE linac is able to produce *macropulses* that are 625µs long and occur at a maximum rate of 120 Hz. During a macropulse the accelerator is "on", that is the ion sources produce beams, pulsed magnets are in the proper states, and the radio-frequency (RF) accelerating fields are on and stable in the linac. During a given macropulse each species of beam is delivered to a single experimental area. The various combinations of beam species and destinations are known as beam *flavors*. The BPM and beam phase measurement systems must be capable of processing signals at this 120 Hz rate; of course presenting data at such a rate to a user is an unrealistic expectation; when collecting data at this rate some analysis will take place within the systems, with a reduced data set being served onto a network for use by users or applications.

*Work supported by the United states Department of Energy under contract DE-AC52-06NA25396

While the beam flavor produced varies on a per-macropulse basis, the pattern of macropulses repeats on 1 one-second-long supercycle.

Within the macropulses the beam time structure varies among the beam flavors. The proton beam that is delivered to the Isotope Production Facility is a flavor dubbed "H+IP". This beam has no time structure imposed on it other than the 201.25 MHz microstructure that is a necessary consequence of RF acceleration.

The H^- beam that gets delivered to the Lujan Neutron Science Center is a flavor known as "LBEG". This beam consists of *minipulses* that are typically 300ns long and occur at a rate of 2.8 MHz. (This is the orbital frequency of the beam in the accumulator ring.) This repetition frequency can be reduced by integer factors, and the minipulse length can be adjusted over a wide range.

H^- beam destined for the Ultra-Cold Neutron Facility ("H-GX") usually has a minipulse structure, though at times this structure is absent.

The H^- beam that is delivered to the Weapons Neutron Research Facility is known as "MPEG". This beam consists of single micropulses, i.e. single RF accelerating "buckets", separated by 1.8µs, though the spacing can be adjusted.

The H^- beam delivered to the Proton Radiography Facility has a highly variable time structure. The minipulses are usually about 60 ns long and are spaced by about a microsecond. There is usually a precursor beam pulse that is used to trigger data acquisition systems for these experiments; this precursor pulse presents the best opportunity for beam position measurements.

The BPM and beam phase measurement systems should be able to provide position measurements for all of these beam flavors, and should be able to provide beam phase measurements, for monitoring and archiving purposes, for those beams with pulses that last long enough for a stable phase measurement.

TIMING SYSTEM

Concurrently with the development of the systems described here, an upgrade of the timing system at LANSCE is underway. The upgraded system will distribute *events* via a dedicated network to each input/output controller (IOC). Distributed along with the events is a *flavor map* that indicates what beam flavors are present during a given macropulse. This scheme will allow the data collected to be identified with a beam flavor. The beam flavor information will be available in the EPICS data records that are served via the control system network. (EPICS is the Experimental Physics

ISBN 978-3-95450-121-2

Industrial Control System, the protocol that will be used on the LANSCE control system network.)

We are strongly motivated to incorporate event receivers into the BPM processors, rather than having analog trigger signals synchronizing the data acquisition. Event receivers are available for a limited number of platforms from Micro Research Finland; the hope is to employ an off-the-shelf event receiver in the BPM processors.

Data acquisition needs to be flexible to allow measurements to serve many purposes. At least 3 modes of acquisitions are presently envisioned: 1) Time-mode, where several (up to about 2000) measurements within a macropulse will be provided for a given BPM. These measurements should be synchronized with the minpulses where appropriate. 2) Per-BPPM mode, with a single measurement per macropulse for each of several BPMs. The system should guarantee that the data sets were collected simultaneously. 3) Gate-stacked mode, where data are collected from a single BPM over the course of many macropulses. This mode requires the system to be able to re-arm at 120Hz to allow data acquisition on consecutive macropulses.

SIGNAL PROCESSING OPTIONS

The signal processing and data acquisition systems under consideration fall into two categories: those that digitize the RF signals from each electrode then numerically process those data ("digitize-early"), and those where the analog RF signals are processed to produce position and phase signals that are then digitized ("digitize-late").

The digitize-early schemes provide flexibility in the processing of the electrode signals into position and phase data, but produce a large volume of data that must be transported among system components and numerically processed. In particular, digitize-early schemes offer the opportunity to provide phase and position measurements from a single transducer. Because each electrode's signal is individually digitized, a large dynamic range is required of the digitizers, and susceptibility to signal noise can be greater than in systems that combine the analog signals before digitization.

The digitize-late schemes produce a more easily handled volume of digital data, but provide very little flexibility in the processing. Very high bandwidth can also be achieved with modest digitization speed.

Libera Single Pass H System

Instrumentation Technologies has a long history of providing signal processing and data acquisition systems for BPMs at many accelerator facilities. They have embarked on a program to develop a similar system to provide position and phase measurements for hadron beams in linacs; the resulting product is the "Libera Single Pass H" system.

This system digitally under-samples the filtered signals from each BPM electrode and the linac reference signal, and provides position and phase data via a network connection to the accelerator control system. Because the position and phase measurements are based upon a single processing chain no splitting or switching of the signals is necessary.

There are thousands of Libera products currently installed in many accelerator facilities; this fact inspires confidence in the system engineering such as temperature regulation, health monitoring, the network interface, etc.

The main concerns with this product are the integration of the event-receiver-based interface to the timing system and the triggering rates that are required. We are actively working with the company to resolve these issues.

We recently purchased a prototype Libera Single Pass H system and bench-top evaluation is in progress. We expect to make beam measurements during the upcoming operating period.

Low-Level RF Control System

As part of a large program of upgrades, including the systems described here, replacement is planned for the control systems for the amplitudes and phases of the radio-frequency (RF) electric fields in the accelerator structures. These new systems directly digitize samples of the 201.25 MHz accelerating fields in the accelerating structures and determine their phases and amplitudes. This is just what is needed for measurement of beam position and phase, so we are exploring that option of exploiting this type of system for our needs. This has the advantage of having a common platform and much of the same software for the two systems, thereby reducing development and maintenance efforts. The system has been designed from the ground up to operate in the context of LANSCE, to interface with the timing system, to provide data compatible with our EPICS control system, and to deal with the various beam flavors.

This system provides up to 7 RF signal inputs, easily accommodating the 5 inputs that the position and phase measurements require: 4 electrodes' signals and a single reference signal from the facility master oscillator. This system has been developed to handle narrow-band signals from the high-quality-factor accelerating structures, so an additional electronics board will be required to provide filtering and other conditioning of the broad-band signals from the transducers for beam measurements.

We anticipate under-sampling the 201.25 MHz beam and reference signals at about 115 MSamples/second. This yields sample streams that can be rapidly fitted to sinusoids using a linearized fitting process that can be implemented in the field-programmable gate-arrays that are provided on the digitizer boards. The amplitudes and phases of the signals can be numerically manipulated to yield measurements of the beam position and phase relative to the reference signal.

AM-PM system

An existing BPM system [1] in a beam transport line has proven to produce measurements that are very valuable; this is "the system to beat" in terms of beam position measurement performance. It employs the

ISBN 978-3-95450-121-2

amplitude modulation to phase modulation (AM-PM) analog processing scheme described in reference [2]. The signals from two electrodes are combined to produce two signals whose phase difference is a function of the beam position. Its main weakness is its decreasing sensitivity for beams that are far from the center of the pipe. This system also does not provide a measurement of the beam phase; some switching or splitting of the signals would be required to provide such a measurement.

This system has very high bandwidth, easily providing measurements of beam position even for minipulses as short as 60 ns. A switchable transversal filter allows measurement of single-micropulse beams by producing a 40 ns-long RF pulse from the single micropulse by means of a series of splitters, delays and combiners.

The analog section of this system provides a trigger at the start of each minipulse; the position and signal intensity signals are digitized after a user-adjustable delay from the minipulse trigger. This self-triggering takes care of the different cable delays among the BPMs.

The system of this type that is presently in use was developed 25 years ago and requires two entire 19″ racks for each BPM. We are currently developing a prototype system that will be smaller, using a modern digital section based on PXI standard modules from National Instruments, Inc.

Analog I & Q Phase Measurement

We presently have an analog system for measuring beam phase; this system is necessary for tuning up the linac after long maintenance periods [3] and the system has performed very well for many years. This system's digitization system and interface to the control system is being decommissioned as part of a larger program, so development of a new control system interface, or replacement of the system, is necessary.

The operation of the system is diagrammed in Figure 1. The signal from the beam is filtered to pick out the fundamental 201.25 MHz component. The filtered signal is then split and a 90° phase shift is applied to one of the two resulting signals via a delay cable. These two signals are then mixed with the reference signal in a double-balanced mixer arranged as a phase detector; this provides I (in-phase) and Q (quadrature) signals that are then digitized and used in a computation of beam phase.

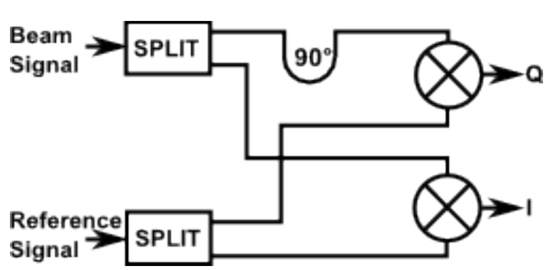

Figure 1: Schematic diagram of the I&Q beam phase measurements system presently used at LANSCE. Its operation is described in the text.

Integrating this system into the new control system at LANSCE would require a modest data-acquisition system, and is an option that can be implemented if funding for the project becomes severely limited.

Analog Integrated Circuit I & Q Detector

Integrated circuits for demodulating RF signals into I & Q components are available, e.g. ADL5387 [4]. The signals from each electrode can be demodulated relative to the reference signal and the demodulated signals can be digitized at a fairly low rate. This would provide signal amplitude and phase information for each electrode, precisely what is needed to determine beam position and phase. This scheme is in its nascent stage; no prototyping or component selection has taken place.

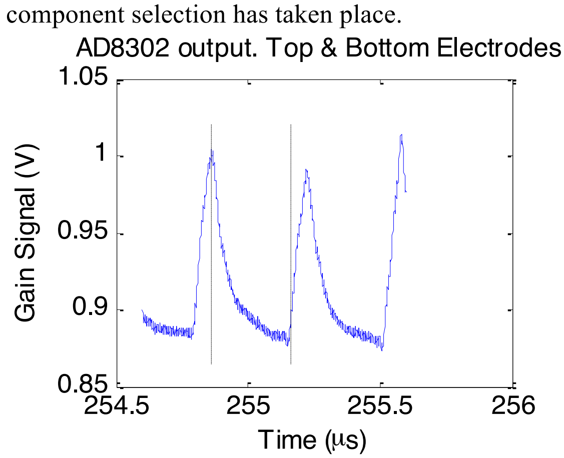

Figure 2: A signal from the AD8302 IC in response to beam signals. The filtered signals from the top and bottom electrodes of a BPM were supplied to the IC as inputs. The dashed lines show a single 300ns-long minipulse.

SUMMARY

New systems for measurement of beam position and phase are under development for LANSCE; we are in the process of evaluating and selecting systems of electronics for processing these signals and serving the data onto the control systems network. Requirements for high bandwidth and high macropulse trigger rates will drive the selection process. Several schemes are under consideration and are in various phases of maturity ranging from conceptual to working prototype. The selection process is scheduled to be completed before the end of 2012.

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ISBN 978-3-95450-121-2