BEAM POSITION AND PHASE MONITORS FOR THE LANSCE LINAC*

R. McCrady, J. F. Power, J. D. Gilpatrick, Los Alamos National Laboratory, Los Alamos, NM 87544 USA.

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 fabricated. 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 and with the RF vacuum feed-throughs. 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. A single transducer will provide signals for both position and phase measurements at each location; these transducers have been fabricated and are presently being installed in the linac. These are known as beam position and phase monitors (BPPMs.)

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 beam, 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 BPPM system 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 BPPM system, with a reduced data set being served onto a network for use by users or applications.

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 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 BPPM system 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 BPPM system, 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 that are

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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 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 BPPM 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 BPPM 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 BPPM. These measurements should be synchronized with the minpulses where appropriate. 2) Per-BPPM mode, with a single measurement per macropulse for each of several BPPMs. The system should guarantee that the data were collected simultaneously. 3) Gate-stacked mode, where data are collected from a single BPPM 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. The digitize-late schemes produce a more easily handled volume of digital data, but provide very little flexibility in the processing.

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 amplitude modulation to phase modulation (AM-PM) analog processing scheme described in reference [2]. The signals from two electrodes are combines 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.

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 BPPM 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.

Digital I & Q system

Another digitize-early scheme [3] involves digital I & Q (in-phase and quadrature) sampling of the RF signals from each electrode; this is illustrated in Figure 1. The electrode signals are filtered to provide a sinusoid at the fundamental frequency of the micropulses, and the sinusoid is sampled at 90° intervals (or at an odd multiple of 90°.) The sampling clock is generated locally from the linac reference oscillator to ensure good synchronization. The I & Q digital samples are then used to determine the amplitudes and phase of the signals from the electrodes.

Development of such a system has begun at LANSCE, however this project has stagnated due to a lack of

engineering resources and the prospects of using other similar systems available from other sources.

The low-level RF control systems for the linac RF power amplifiers that is under development uses a digital I & Q system and preliminary investigations into employing that system, with suitable modifications, have begun.

National Instruments is presently developing a similar system using the PXI platform with currently-available modules for sampling and FPGA-based preprocessing of the voluminous digital data.
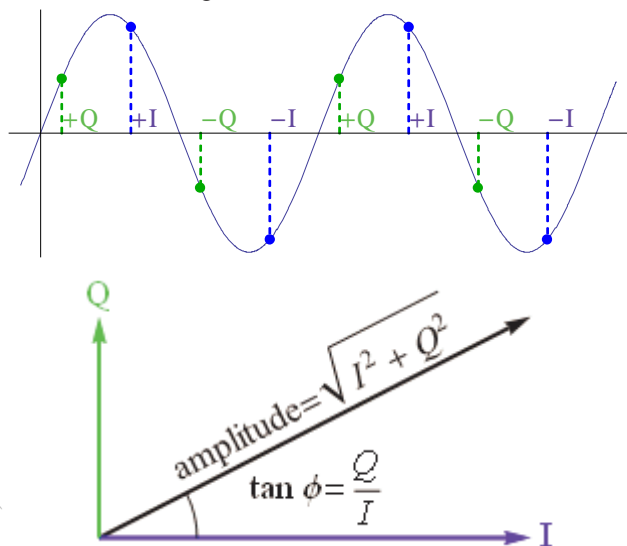

Figure 1: Digital I & Q is illustrated. The top figure shows how data samples collected at 90° intervals of a sinusoid can be interpreted as I and Q data. The bottom figure shows how these data can be used to compute the amplitude and phase of the wave. Relative to the sampling clock.

Analog Gain & Phase Detector

The AD8302 integrated circuit (IC) from Analog Devices, Inc. is designed specifically to compare the amplitudes and phases of two RF signals [4]. This presents possibilities for use in BPPM systems. The small signal envelope bandwidth for this IC is quoted as 30 MHz, casting doubt on its use for beams with 300 ns-long minipulses, and especially for single-micropulse beams.

Figure 2 shows the log-ratio output of the AD8302 with signals from the top and bottom electrodes of a BPM supplied to the two RF inputs of the IC. (The electrode signals were passed through 250 MHz low-pass filters.) The output of the IC doesn't stabilize during the 300 ns-long minpulse. Because of this insufficient bandwidth this line of development has been abandoned.

Analog I & Q Detector

Integrated circuits for demodulating RF signals into I & Q components are available, e.g. ADL5387 [5]. 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.
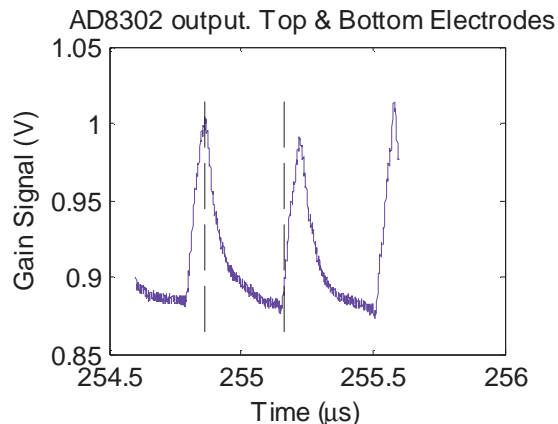

Figure 2: A signal from the AD8302 IC in response to beam signals. The filtered signals from the top and bottom electrodes of a BPM were supplied to the IC as imputs. The dashed lines show a single 300ns-long minipulse.

SUMMARY

A single transducer at each of several locations will provide beam signals for measurement of beam position and phase in a new system under development for LANSCE; we are in the process of evaluating and selecting a system 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 2011.

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