SPALLATION NEUTRON SOURCE LINAC BEAM POSITION AND PHASE MONITOR SYSTEM*

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Abstract

The SNS linac currently has over 60 beam position monitors which allow the measurement of both beam position and phase from a single pickup. The signals from the pickup lobes are down converted from either 402.5 MHz or 805 MHz to 50-MHz IF signals for processing. The IF signals are synchronously sampled at 40 MHz to generate I and Q signals from which the beam position and phase are calculated. Each BPM sampling reference frequency is locked to a phase-stable 2.5 MHz signal distributed along the linac. The system is continuously calibrated by generating and measuring rf bursts in the processor that travel to the BPM pickup, reflect off of the shorted BPM lobes and return to the processor for re-measurement. The electronics are built in a PCI card format and controlled vith LabVIEW. Details of the system design and performance are presented.

INTRODUCTION

The beam position and phase measurement system consists of the beam line position pickups and their Heliax® transmission cables, PC-based BPM electronics with LabVIEW® control software , reference frequency distribution system, and physics applications software[1-4].

Depending on the location of the position pickup in the accelerator, the signals measured are either 402.5 or 805 MHz. These signals connect via relatively long Heliax® cables to the BPM PC, which contains a custom PCI card that processes the signals. The input signals are down-converted to 50 MHz IF signals on a custom 4-channel analog front end (AFE) card designed and built buy Bergoz Instrumentation to meet our specifications [5].

Figure 1: The custom PCI BPM data acquisition card.

The four IF signals are sampled at 40 MSPS to generate in-phase and quadrature (I&Q) signals that are passed to the LabVIEW® instrument software for analysis.

The beam position is calculated from the magnitudes of each of the four BPM electrode signals. The signals from all four electrodes are summed and both the magnitude and phase of the resultant is calculated as a measure of beam phase and the approximate beam current. The phase measurement of each BPM is absolute, relative to the master reference signal with an accuracy of about 2 degrees rms at the RF frequency.

CALIBRATION SYSTEM

The BPM system is self calibrating. The calibration process runs continuously in the background without user intervention.

The calibration is made possible by fast-switching networks on the inputs to each down converter channel. A calibration signal, at the same frequency as the beam signals, can be switched to either the input to the down converter, or to the cable connected to the AFE input. The third switched condition is the normal operation one in which the AFE inputs are connected directly to the down converter inputs.

The technique is basically the same as a time domain reflectometer (TDR), except we use a rf burst instead of a step function. This is made possible by using rather long cables between the AFE and the BPM pickups, and by using pickups that have the downstream end of each lobe shorted.

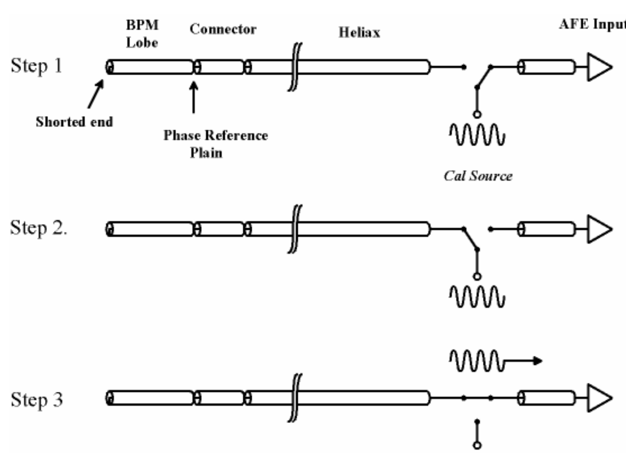

Figure 2: The calibration uses an rf burst to calibrate the down converter chain in step 1, launch a calibration burst down the BPM Heliax® cable in step 2 and measure the reflected burst in step 3.

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The first step in the process is to inject a rf burst into the input of a down converter channel and measure the amplitude and phase of the result. Next is to launch a burst of the same amplitude into the cable connected to the AFE input. This cable has a round-trip transit time of at least 300 ns, which determines the maximum length of the calibration burst. This burst reflects off of the shorted end of the pick-up and returns to the down converter input, which is switched in at the time of arrival of the reflected pulse. Having measured the amplitude and phase of the reflected pulse, one has enough information to calibrate the system in amplitude and phase through the entire signal path.

The AFE calibrator circuit is carefully adjusted to give the same amplitude and phase of calibration bursts to each channel by tweaking a resistive splitter on the AFE circuit board.

Actual calibration waveforms are shown in Fig. 3 as observed within the LabVIEW® application. Data from two of the four lobes is shown. Since there is some coupling between the four lobes of the BPM, on the order of -30dB, it is necessary to calibrate the four lobes at different times to remove this effect.

We currently use 4 µs to calibrate each channel for instances in which the BPM cable lengths are 150 ns each way. The 4 µs gives more than enough time for any reflections to damp out prior to the next calibration pulse cycle. A complete calibration cycle for four lobes takes 16 µs. This process is repeated about 50 µs before each beam-pulse data array is taken, and at the same rate. Multiple calibration pulses are continuously averaged to get data that is stable to a few milli-degrees.

Since the cable lengths vary along the linac and beam transport lines, the calibration timing is adjusted appropriately.

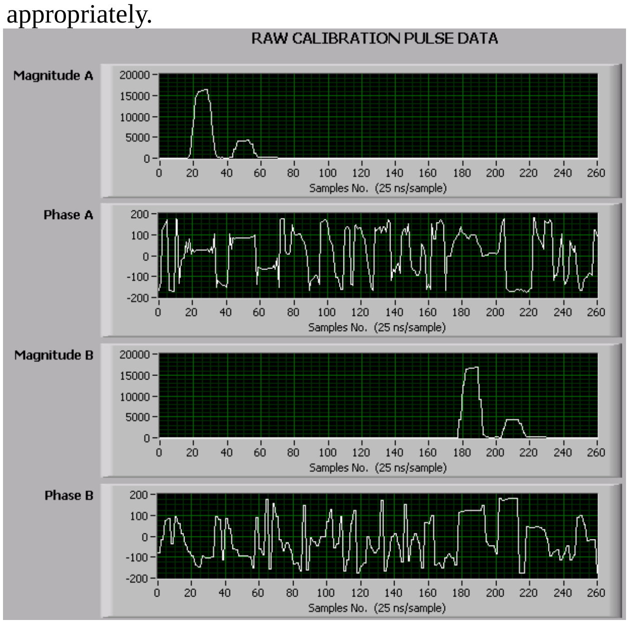

Figure 3: Typical calibration waveforms seen within the LabVIEW® application for two of the four channels. Note that the phase signals are random noise without the presence of a calibration signal pulse.

BPM RF REFERENCE DISTRIBUTION

Absolute phase measurements can be made between any two BPMs in the machine thanks to the BPM rf reference distribution system[3]. This is a fiber-optics-based system that delivers the required reference frequencies to each BPM chassis throughout the facility. These frequencies include 2.5, 352.5, 402.5, 755 and 805 MHz (the 2.5 MHz signal is used to phase-lock the 40 MHz BPM IF sampling ADC clocks). These signals are injected onto a single fiber that links all of the BPM rack locations. At each BPM location the fiber is tapped and the rf frequencies are detected, amplified, and distributed to each BPM chassis in the same equipment rack area.

Careful selection of optical components has lead to a phase stability of about 1 degree rms over the nominal temperature cycles observed throughout the SNS linac equipment building. This stability could be improved by temperature stabilization of the fiber optic transmitter and receivers used.

BEAM SIGNALS

Typical beam signals as seen within the BPM instrument LabVIEW® software can be seen in figures 4 and 5.

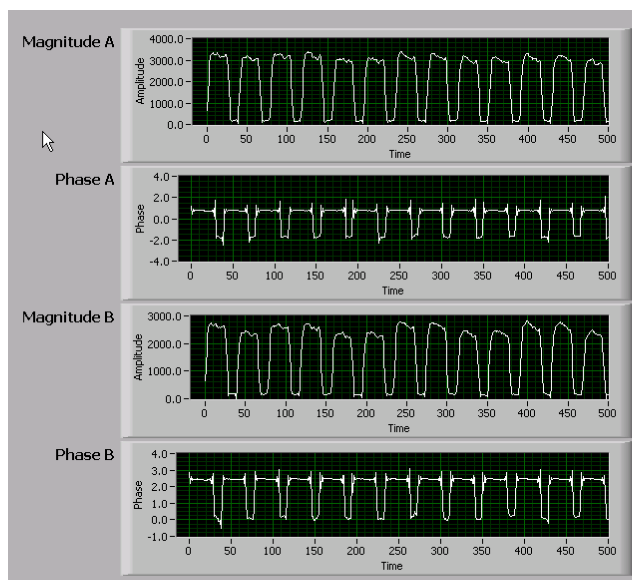

Figure 4: Actual beam signals for two lobes within a position pickup. The ratio of magnitudes would be processed to give the position measurement. The beam is chopped for injection into the storage ring.

These are the raw signals in Fig. 4, from which the position and phase are calculated. The ratio of the magnitudes is used in the position calculation and the vector sum of the four magnitude signals is used in the phase and amplitude calculations. There are no current transformers in the SNS linac following the DTL sections so the BPMs are calibrated as current monitors in the CCL and SCL portions of the linac. For centered beam, these measurements can be calibrated fairly accurately and are very useful.

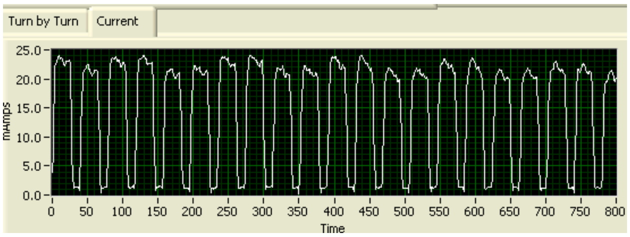

Figure 5: The BPM system is also used as a beam current monitor as there are few beam current transformers in the linac.

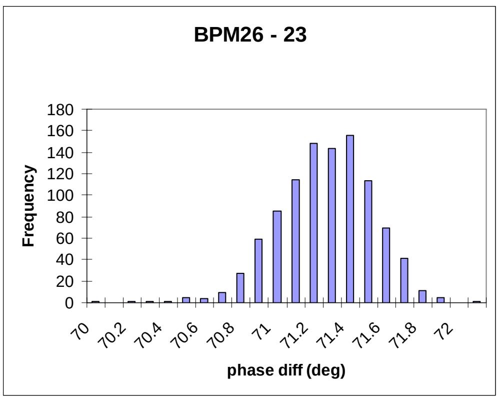

Figure 6: A typical histogram of the differential-phase measured between two BPMs whose electronics are in the same rack are. The data is 1000 beam pulses, averaged over 20 µs. The jitter is 0.26 degrees rms.

The typical differential jitter measured between two BPMs located in the same rack area is on the order of 0.26 degrees rms as shown ion Fig. 6. This graph is for 1000 beam pulses, with the phase averaged over 20 µs in each pulse.

Systems within the same rack area use common fiber optic receivers for the reference frequencies, so the receiver phase noise is largely removed in the differential measurements. This is the mode used in most of the phase measurements.

LINAC TUNING WITH BPM PHASE DATA

The BPM system is used to provide the beam phase data needed for tuning the linac rf systems. We use an extension the classic phase scan method. A special control system software application, PASTA, has been developed at SNS to automate and enhance this process using use a signature matching method[4].

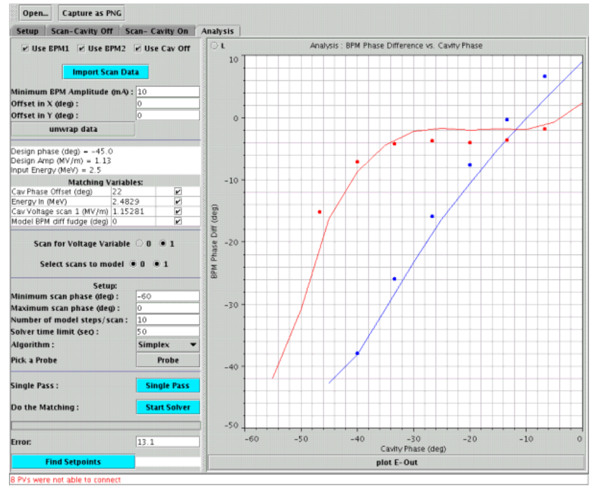

Figure 7: A typical PASTA data analysis window.

In Fig. 7 we have a typical data analysis screen from the PASTA application. Shown are measured phase values relative to the theoretical response. Data of this type is taken for all of the accelerator cavities and used to determine the proper cavity phase and power set points.

CONCLUSION

The BPM system used by the SNS linac provides both beam position and beam phase data sufficient to properly determine the linac rf cavity phase and power settings in a timely manor.

REFERENCES

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[5] Julien Bergoz and Klaus Unser, Bergoz Instrumentation, Saint Genis Pouilly, France, http://www.bergoz.com/.