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ANALOG APS LINAC PHASE DETECTOR AND DIGITAL PHASE DETECTOR TEST COMPARISON*

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Abstract

Maintaining beam-accelerating structure rf phasing of a linac is crucial for maintaining optimal beam transport performance. At the Advanced Photon Source (APS), in 2008 we implemented an analog phase detector system using the Analog Devices AD8302 phase detector chip. The APS phase detectors use as an S-Band rf phase reference an outcoupled signal from the waveguide supplying the accelerating structures with rf and an S-Band filtered rf signal from a beam position monitor (bpm) for the beam-rf system phase measurement. The phase detectors are used throughout the length of the linac in a control law to automatically maintain the beam on-crest phase condition during operations. We have obtained from Instrumentation Technologies two phase detection systems we evaluated as a possible upgrade path for the legacy APS phase detector system. The systems are the Libera LLRF and Libera cavity bpm products available from Instrumentation Technologies. We compare the performance of each system to induced phase changes using the APS Linac rf thermionic gun electron source.

INTRODUCTION

The APS linac analog phase detector system using the AD8302 phase detector processor has been previously described [1, 2]. Figure 1 shows the layout of the analog phase detector board outlined in red dashes. The S-band filtered bpm signals are summed then passed to the AD8302 phase detector as the signal whose phase is to be measured. The other input is the coupled output of the S-band accelerating structure waveguide signal used as the phase reference. The phase detector measures the phase (and log-ratio amplitude of the bpm and reference signals) then the signal is digitized and sent to EPICS. The Linac rf runs at 30 Hz repetition rate and the beam rate is any rate less than or equal to 30 Hz. The AD8302 is triggered off the beam so there is always a valid phase (and amplitude) signal available in EPICS.

The AD8302-based phase detectors are somewhat finicky and require careful configuration, which is unique for each device. The response of each module depends on the levels of each input signal, as well as the phase relationship between the two signals. This greatly complicates the availability of spare modules and the ability to change or expand the existing system. For a more robust phase detector in the years to come, it would be advantageous to use a commercially available solution.

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PHASE MEASUREMENT METHOD

When testing the Instrumentation Technologies Libera LLRF and Cavity bpm systems, the same bpm and rf signals were used as in the tests of the AD8302 phase detector. The bpm signal used the bpm just downstream of the rf thermionic gun alpha magnet (just upstream of the first linac accelerating structure L2:AS1) and the rf reference was a coupled output of the rf thermionic gun waveguide. Phase shifts were induced by adjusting the rf thermionic gun power which results in an arrival time change at the downstream bpm due to the dispersion of the alpha magnet (see Fig. 2). All three phase detector responses to bpm arrival time changes were measured and compared.

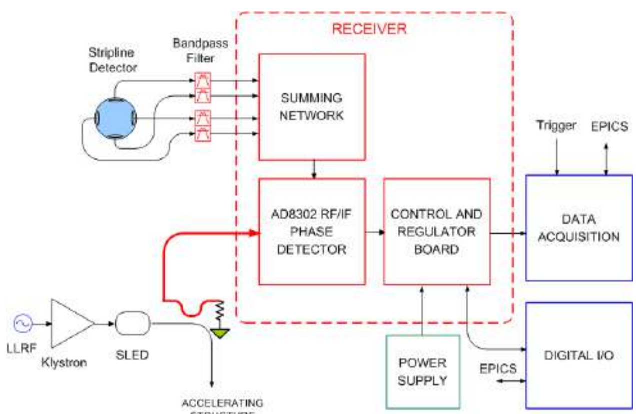

Figure 1: Block Diagram of AD8302 phase detector board (denoted by red dashes) showing bpm and linac rf phase reference inputs and EPICS output.

INSTRUMENTATION TECHNOLOGIES LIBERA LLRF TEST

The Libera LLRF product [3] developed by Instrumentation Technologies is used for digital stabilization of amplitude and phase in accelerating structures. Built into the product is the ability to measure the phase of various signals in the rf signal chain relative to the accelerator master oscillator rf frequency. We tested the Libera LLRF electronics as a phase detector by splitting the bpm signal ap plied to the AD8302 phase detector electronics and using the resulting 3dB lower signal as input to an unused phase channel of the Libera LLRF (see Fig. 2). This way we could directly compare both phase detectors at the same time (acquire phase PVs as the rf thermionic gun rf was varied). The Libera LLRF uses the linac master oscillator continuous wave (CW) source as its phase reference (2856 MHz) and the rf thermionic gun power was varied to change the arrival time at the bpm.

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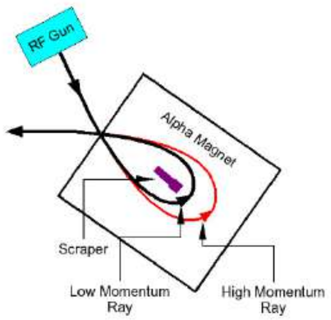

Figure 2: Diagram showing how rf gun power affects arrival time via alpha magnet dispersion.

Libera LLRF was triggered at the rf modulator rate (30 Hz) and not the beam, so we acquired ~500 phase waveform samples and filtered out the ones that were valid and obviously not noise (due to no beam being present). The results are shown in Fig. 3, where the Libera LLRF phase output is plotted against the AD8302 phase output. The large error bars are due to some large outliers for Libera LLRF and likely also due to the relatively small bpm arrival time signal. The bpm signal suffers from lowering due to the S-Band filtering and also splitting the signal at the AD8302 phase detector. However, the slope of the curve is seen to be unity indicating that both phase detectors read correctly changes in phase at the S-Band frequency.

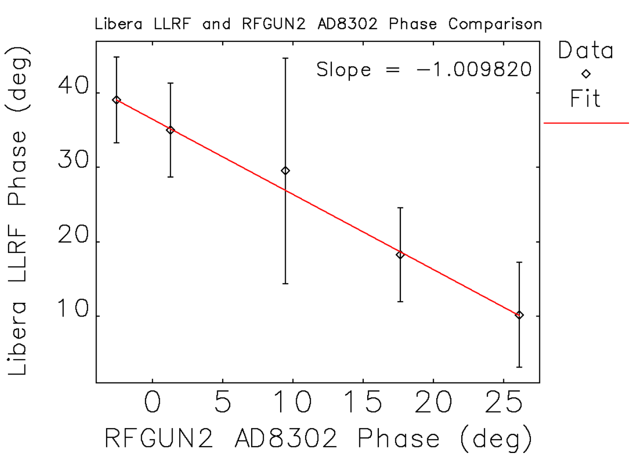

Figure 3: Plot of Libera LLRF phase output vs the AD8302 phase output as the rf thermionic gun power was varied.

INSTRUMENTATION TECHNOLOGIES LIBERA CAVITY BPM TEST

The Libera Cavity bpm instrument [4] developed by Instrumentation Technologies is intended for use in linacs to measure beam position from cavity-type beam position monitor pickups. After testing the Libera LLRF device, Instrumentation Technologies suggested that the cavity bpm electronics could also be used to measure the phase relationship between the beam signal and a reference input, and provided a temporary trial unit that was configured for our operating frequency of 2856 MHz. Unlike the LLRF unit, the cavity bpm allows triggered acquisition to collect beam and reference signal phase information for each beam pulse. These raw signal ADC waveforms can then be post-processed offline to measure the phase relationship between the signals.

Connecting the same bpm signal and rf reference applied to the inputs of the cavity bpm, we repeated the phase measurement. With a nominal rf gun charge of 0.75nC per pulse, we collected data for various rf thermionic gun power settings and processed the results to compare with the existing phase detector system. Due to scheduling limitations, we were only able to collect a limited amount of data with the cavity bpm electronics during our trial period. A comparison of the phase change measured by the existing system and the cavity bpm is shown in Figure 4.

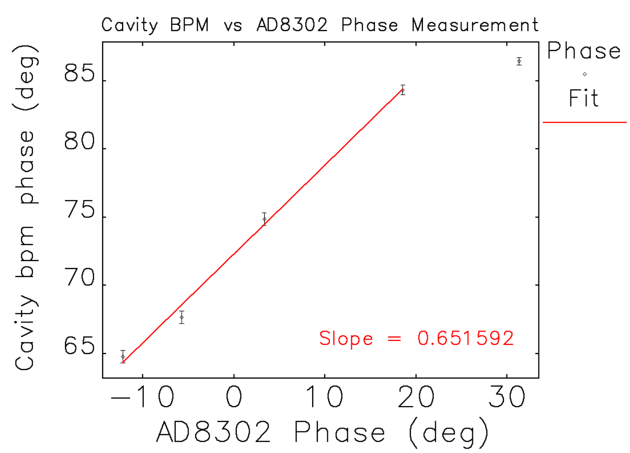

Figure 4: Plot of Libera Cavity bpm phase calculation vs AD8302 phase output as the rf thermionic gun power was varied.

A comparison of the phase measurements of the Libera devices versus the AD8302 phase detector are shown in Figure 5. The Libera LLRF phase measurement corresponds well with the AD8302 system over the entire range of rf gun power. The cavity bpm results are fairly linear from an rf gun power level of 2.5 MW to 3.45MW, but has an unexpected difference at the lowest power level around 2.0 MW. The cause of this difference is unknown.

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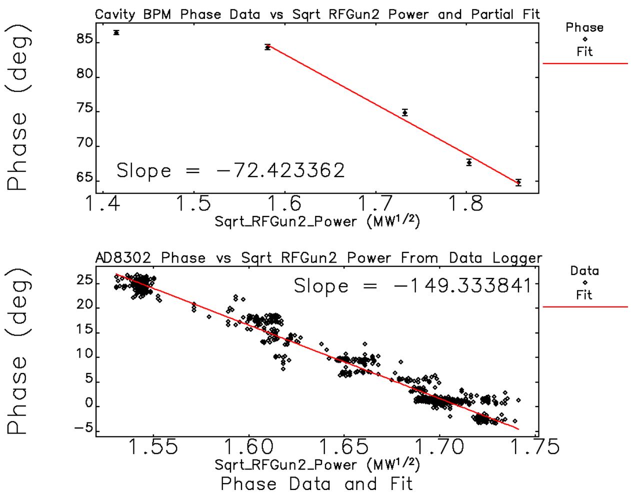

Figure 5: Measured phase vs square root of rf gun power for the Libera LLRF (top) and Libera cavity bpm (bottom).

CONCLUSIONS

Two devices from Instrumentation Technologies were evaluated as a potential upgrade for the existing phase detector system in the APS linac. Both systems demonstrated the capability to measure the phase relationship between the beam signal from a bpm and the rf accelerating structure reference signal. Using our existing Libera LLRF system as a phase detector requires collecting large amounts of data and selecting only the samples of interest and is somewhat limited by the very low signal levels available to the electronics. The Libera cavity bpm is much more suited to the task of phase detection, as it is capable of triggered operation to capture beam signals as well as better performance at the low signal levels available from the bpm. Further studies are needed to better understand performance under a variety of conditions, but the cavity bpm appears to be a promising candidate for an upgrade solution.

ACKNOWLEDGEMENTS

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[3] Instrumentation Technologies Libera LLRF, `https://www.i-tech.si/particle-accelerators/products/libera-llrf`

[4] Instrumentation Technologies Cavity BPM, `https://www.i-tech.si/products/libera-cavity-bpm`