IMPROVEMENTS TO EXISTING JEFFERSON LAB WIRE SCANNERS*

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Abstract

This paper details hardware and protocol changes for selected CEBAF wire scanners to improve the quality of beam profile measurement and determination of beam properties. A photo-multiplier tube based data path improves noise floor and dynamic range, and a new scan protocol, more efficiently interleaving wire motion and beam transport parameter changes, reduces dead time. Presented will be the status of the design, prototype results and a comprehensive upgrade plan.

INTRODUCTION

The CEBAF accelerator simultaneously delivers highly polarized (<=90%) CW electron beams of up to a 6 GeV energy to up to three fixed-target experiments. Upgrades are under way increase the energy to 12 GeV and enable simultaneous beam delivery to four experiments. A pair of anti-parallel superconducting linacs, connected by normally conducting recirculation arcs, accelerate the beam up to 5 times (6 for the first linac). The revised beam structure interleaves six 249.5 MHz RF buckets into a combined 1497 MHz beam for acceleration. [1] Individual beam current may vary from several pA to hundreds of uA, with total beam power being limited by the 1 MW dump capacity.

Profile monitors at CEBAF are principally wire scanners. Beam size and absolute position are used to infer the energy, energy spread, and Twiss parameters of the beam. Partly because of ruggedness, these are dominantly first-generation devices, with data acquisition driven by Camac-based stepper motors and Aurora 12 (or 14) transient recorders. Special-purpose installations on each of the extraction lines to the experimental halls have resulted in some variation in the system configuration. Performance requirements for 12 GeV upgrade diagnostics [2] include a spatial resolution of 25 um, relative position accuracy of 50 um, and a transverse range of widths from 25um < $\sigma_{x,y}$ < 2.5 mm for beam currents ranging from 1 nA up to 20 uA, with due consideration for construction of the wire scanner and the duty factor of the beam.

The synthesis of a scalable, commercially available installation with a variety of hardware and software improvements supporting improved peak detection and reduced noise and analytical error will be presented herein. Reduced execution time and increased accuracy / precision will improve beam characterization capacity with benefits to both accelerator and experimental physics divisions.

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EXISTING INSTALLATION

Accelerator/CEBAF Wire Scanners

Our typical scanners consist of a Camac-based transient recorder directly coupled to Tungsten-Rhenium, Iron, or Carbon filaments on a polymer support fork. Secondary electron current from beam impact is digitized following analog amplification. This direct coupling results in signal contamination from both ground loop noise and synchrotron light stimulated photo-emission. The standard (first-generation) protocol moves the carriage to the “in” limit switch, then to the “out” limit. The axis of motion is rotated by 45 degrees from horizontal. Multiple wires mounted on a single fork provide horizontal, vertical, and one 45 degree profile projection per scan. Carriage position is obtained from the digitized signal of a linear potentiometer attached to the carriage.

Scaler/PMT–based Detection

Profile measurements for beam currents as low as hundreds of pA are obtained in the Hall B line via VME-based scanners using PMTs/scalars to count event rates from the radiation shower field. Such rates are directly proportional to the beam current incident onto the scanner wire, with extremely low background. With a reduced carriage velocity compared to other CEBAF wire scanners [3] to compensate for reduced beam current, the beam profile obtained from the integrated event count vs. carriage position provides a typical dynamic range of 5000:1.

Super-harps

Scanners known as super-harps installed in some Hall beam lines are similar in design and construction to the CEBAF wire scanners, but use co-located beam loss monitoring (BLM) system PMTs (Hamamatsu Model R931b) instead of separate signal amplifiers. Data from instantaneous tube current rather than from event rate provides a noise floor intermediate between standard and Hall B scanners. These scanners must supply precise absolute beam position data, so the carriage position is obtained from absolute encoder readings rather than from a potentiometer. [4]

Proposed Hardware Modifications

A bench tested super-harp carriage supported by an updated interface chassis will be installed in the beam line upstream from the RF elements extracting beam to the experimental halls. This chassis uses rack space efficiently, consolidating stepper motor control, limit switch positioning, pre-amplifier output, and encoder positioning. [5] Standard BLM PMT detectors will initially be employed, but will be optimized after future studies of spectral response, location, and detection

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geometry [6][7] Test PMTs will be independently powered across a nominal -1 to -1.5 kV functional range by a CAEN V6533N VME-based supply. This will allow for a study of operating voltage with respect to rates, dark current, and burn in effects on the system. The PMT setup will be able to be (un)monitored as desired for the purpose of a measurement, though by design this necessitates that the PMTs remain on to avoid the above named effects. The modified hardware will have an operable current range down to the tens of pA level.

On the hardware level, a switch from the Aurora 12/14 transient recorder to the CAEN model V1720 Digitizer provides firmware support for charge integration, pulse processing, and modification of triggering and trigger thresholds to improve data acquisition performance. [8] It is hoped that improved dynamic range may be obtained through pipeline signal processing methods and noise suppression via software on the IOC / Digitizer / FPGA level. Methods being tested include Fourier analysis of the signal in the frequency domain and implementation of removable software filters to eliminate known noise sources present on the beam. Potential noise sources in CEBAF include diagnostic beam modulation frequencies near 400 Hz and 60 Hz line noise. This may in turn be augmented by clock synchronization to one of a variety of sources.

As Table 1 shows, the improved digitizer supports significantly denser data, improving sample statistics. Firmware will allow the augmented wire scanner to function similarly to an oscilloscope on the beam with all of the implied benefits. This approach is entirely VME-based, reducing our dependence on aging CAMAC hardware. The capacity of the digitizer to be internally or externally triggered/synchronized, as well as networked to other digitizers, provides an extensible architecture covering all anticipated accelerator needs, including accounting for the effect of beam position jitter measured by BPMs near the wire scanner.

DATA PROCESSING METHODS

Existing Data Processing Methods

Wire scanners are the primary means by which emittance and Twiss parameters are measured and calculated in CEBAF. The existing method of data collection is known as the ‘Multi-harp Emittance Tool’. Using this tool, a series of wire scanner data are taken and fitted via use of an operator gated GUI interface which makes fixed changes to a specified upstream quadrupole while the operator initiates the wire scanner of choice. The application interprets the profiles via a peak fitting algorithm, allowing the operator to skip points or rescan profiles in case of data failure. Data sets converted via a series of Perl scripts into a suitable format are processed by elegant/SDDS tools which fit the data, returning Twiss parameters and recommended optics changes, for example, to optimize matching between accelerator segments. [12] Features enabling identification or removal spurious/outlying data within the set are presently absent, which may lead to sub-optimal matching results in the shell scripts are blindly run.

Proposed Software Modifications

A modified scan protocol using partial strokes of the wire scanner, interleaved with optics changes, provides multiple beam profiles per digitizer buffer. Avoiding the dead time of full-stroke scanner sweeps for each optics setting reduces the execution time by an order of magnitude (from 30-45 minutes down to less than 5 minutes) with unchanged hardware, requiring only ioc level support. A data visualization and selection procedure tested earlier has been adapted to the control room OS (Red Hat Enterprise Linux 6) with transfer functions from the accelerator elegant model. [13] This coupled with the ability to deselect outlying datum allows for a more expedient and accurate method by which to compute an optimal match at a given point in the beam line for those input conditions.

Another improved interface (qsUtility) using an API library (HAPI) being developed by M. Keesee in the AHLA group supports similar features while extending data processing functionality through support of peak location and fitting algorithms such as wavelet space analysis for noise reduction [14] and genetic algorithms to assist in fitting peaks within the data set [15]. Such methods are currently under investigation for application by various members of the CASA and AHLA groups, as is the integration of these tools/protocols before the restart of operations.

CONCLUSIONS

This upgrade unites improvements already proven in field installations of wire scanner subsystems, and will result in hardware consolidation and improved current range and transverse position resolution. An order of magnitude improvement in execution time due to a protocol change, linked with a capacity to identify and deselect outlying points in the data set, will result in faster, more reliable determination of beam Twiss parameters and emittance, and consequently improved beam handling. Reduced execution time will make comparative studies of the interleaved beams in the CEBAF accelerator feasible, and allow experimental quantification of current dependence.

Improved noise floor and dynamic range from sampling/clock synchronization, PMT-based data acquisition (using direct-coupling or scaler-based event counting), digital filtering, pipeline processing, and other algorithmic improvements will result in improved beam characterization quality and reliability. PMT optimization and algorithmic improvement holds great promise for the future.

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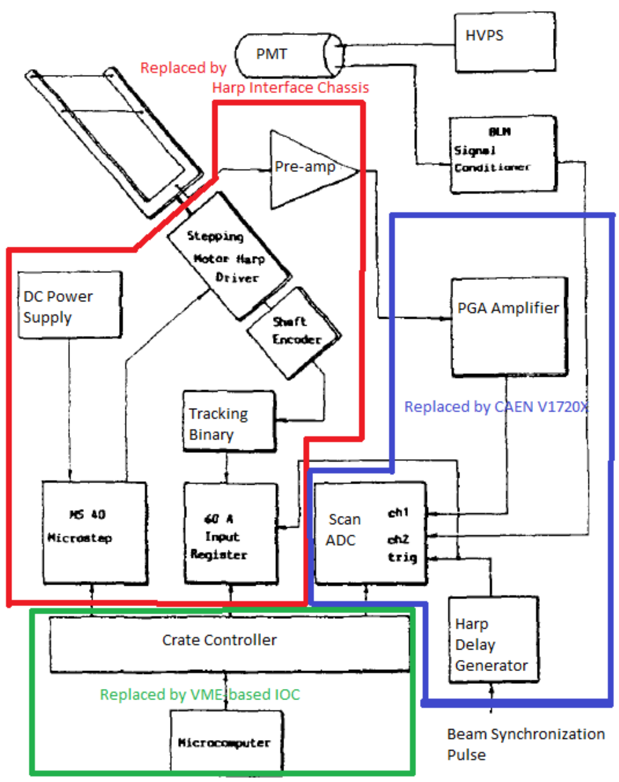

Figure 1: A diagrammatic sample of hardware reduction between the existing and modernized systems.

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Table 1: Transient Recorder / Digitizer Specifications

Digitizer:	Aurora 12 [9]	Aurora 14 [10]	CAEN V1720 [8][11]
*Channels	6	6	8
Aperture Jitter	100 psec	40 psec	< 100 ppm
Max sample rate	DC- 100 kHz	DC- 1 MHz digitizing	250 MS/s
Memory: SRAM/Board Memory Samples/ch.	8k word x12bit cmos/per channel	128k x 12 bit/ch. 512K / 1024K optional	1.25 MS/ch, C4, single ended input, 10 MS/ch. optional
Bandwidth	100 kHz (analog)	750 kHz (analog)	125 MHz
Full Scale Range (V)	10	20	2 w/ +/- 1V offset adjust
Form factor/ Package	CAMAC	FASTCAMAC	6U-VME64/VME64X
Interface	Analog	FASTCAMAC (7.5MB/s)	VME64X (60 -120 MB/s), CONET(80Mb/s), USB(30Mbs)

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