WIDE-BANDWIDTH CAPTURE OF WIRE-SCANNER SIGNALS*

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Abstract

Integrated charge collected on the sense wires of wire-scanner systems utilized to determine beam profile is generally the parameter of interest. The LANSCE application requires capturing the charge information macropulse-by-macropulse with macropulse lengths as long as 700 μs at a maximum macropulse rate of 120 Hz. Also, for the LANSCE application, it is required that the integration be performed in a manner that does not require integrator reset between macropulses. Due to the long macropulse which must be accommodated and the 8.33 ms minimum pulse period, a simple R-C integrator cannot be utilized since there is insufficient time between macropulses to allow the integrator to adequately recover. The application of wide analog bandwidth to provide accurate pulse-by-pulse capture of the wire signals with digital integration of the wire signals to determine captured charge at each macropulse in applications with comparatively long macropulses and high pulse repetition rates is presented.

INTRODUCTION

The maximum macropulse repetition frequency (PRF) of the LANSCE accelerator is 120 Hz [1], and the maximum macropulse width is nominally 700 μs [2]. The overall requirements for the LANSCE wire-scanner systems are given in reference [3].

The wire-scan profiles are collected pulse-by-pulse with the wire position moved between macropulses. The wire current from a single macropulse is collected at each wire position. The minimum macropulse period of 8.33 ms is nominally a factor of ten greater than the maximum pulse width. The long pulse width at the high PRF results in a comparatively high duty cycle. This high duty cycle presents a significant challenge in accurately capturing pulse-by-pulse charge information.

The typical wire-scanner parameter of interest is the total charge collected by the sense wire during each macropulse. The wire signal is a current, and this current is typically collected using a transimpedance amplifier and integrated to provide the total integrated charge.

A disadvantage of applying simple integration is that the integrator must be reset between macropulses. This complicates the data acquisition since a reset command must be delivered to each wire-scanner system.

An R-C integrator, also termed a lossy integrator, may be utilized if the integrator time constant is sufficiently longer than the pulse width. Generally, the time constant should be at least a factor of 10 greater than the pulse width to be integrated to assure accurate integration.

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Since the LANSCE minimum macropulse period is 8.33 ms, and the maximum macropulse width is 700 μs, the use of a simple lossy integrator would be problematic.

LOSSY INTEGRATOR

A lossy integrator is simply an R-C low-pass filter having a sufficiently long time constant in comparison to the signal to be integrated that the output voltage developed on the capacitor is substantially the integral of the input signal.

Figure 1 is a simulated example of 1 mA, 700 μs pulse integrated using a transimpedance amplifier and an R-C integrator having a 10 ms time constant, e.g., 150 ηf capacitor and 66.5k-Ohm resistor.

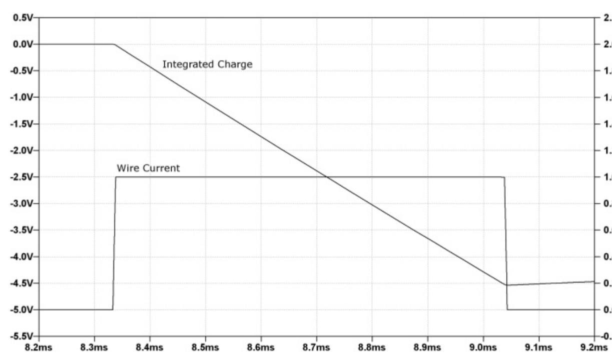

Figure 1: Lossy integrator integration response.

The true integrated charge of the 700 μs long 1 mA pulse is 700 ηC. The magnitude of the integrated potential on the 150 ηf integrating capacitor is 4.55 V, and the integrated charge collected on the integrator capacitor is 683 ηC. The 10 ms R-C integrator introduces a nominal 2.4 percent error in the integration of the 700 μs pulse.

The error may be reduced by increasing the R-C integrator time constant. However, a longer time constant will require a longer integrator recovery time. Although the simple R-C integrator provides acceptable integration of single pulses, it can introduce considerable error when integrating multiple sequential pulses. Figure 2 shows the response of the same integrator of Fig. 1 integrating multiple macropulses.

The current signal of Fig. 2 has a PRF of 120 Hz and a pulse width of 700 μs both matching the LANSCE boundary conditions noted above. In Fig. 2, the first integration begins at an initial condition of zero charge on the integrating capacitor. The second transition occurs before the integrator has recovered from the first current pulse. This results in an error in the integration of the second current pulse. Specifically, the integration of the

ISBN 978-3-95450-115-1

second current pulse results in a 4.37 V change in the potential on the integrating capacitor corresponding to a charge of 655 ηC. The integration error of the second current pulse is nominally 6.4 percent.

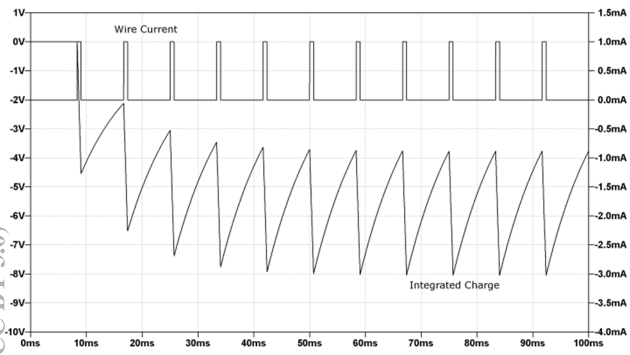

Figure 2: Lossy integration of multiple pulses.

This error increases with the number of current pulses to a steady state value of nominally ten percent for the signal of Fig. 2 at the tenth pulse, e.g., ~4.2 V integrator potential change, 630 ηC, and an error of ~ten percent. This type of error is often termed pulse pile-up error where the pulses in effect pile up on each other.

If the current pulses in Fig. 2 were actual wire-scanner wire-current signals, and where each wire signal is collected at a different position in the beam, each integrated value would have this pile-up error introduced by the failure of the integrator to fully recover between pulses. As a result, very significant error would be introduced in the projected beam distribution computed from these data. The integration accuracy and the recovery time of the lossy integrator are conflicting parameters, and a trade-off is necessary when this method is utilized in the integration of repetitive pulses.

The signals such as seen in Fig. 2 are analytic, and the data may generally be post processed to deconvolve the pulse-by-pulse charge information from the raw data. However, this process requires somewhat complex data processing, and as a result the deconvolved signals may not be available real time. Timely availability of profile data is typically critical, during machine tuning for example.

DIGITAL INTEGRATION

The LANSCE wire-scanner systems, utilize a comparatively wide-bandwidth BiRa Model 3443 transimpedance-amplifier cRIO module as the Analog Front-end Electronics (AFE) to collect the wire-current signal. The transimpedance amplifier output is a voltage proportional to the wire current with a gain of nominally 5,000 Ohms. This voltage signal is digitized using a cRIO NI9222 digitizer. The sampled data is digitally integrated using the computational capability of the cRIO real-time processor (cRIO RT processor) to provide the charge captured by the sense wire.

The bandwidth of the AFE is a trade off between signal integrity and noise. The design goal was to provide a nominal 1 µA RMS noise floor at the full AFE bandwidth, and a 1 mA full-scale AFE input. The desired noise floor is achieved with an AFE analog bandwidth of 35 kHz. An analog anti-aliasing filter well above the 35 kHz pole is also utilized to eliminate aliasing in the digitizing process.

A convenient sample rate of 500k samples/second is utilized which provides 350 samples in a 700 µs macropulse. The complete macropulse is digitized, and integration of the sampled data collected over the macropulse is performed in the cRIO RT processor immediately following capture of the pulse data.

A typical AFE output signal is shown in Fig. 3 where the vertical wire is deployed in the beam [4].

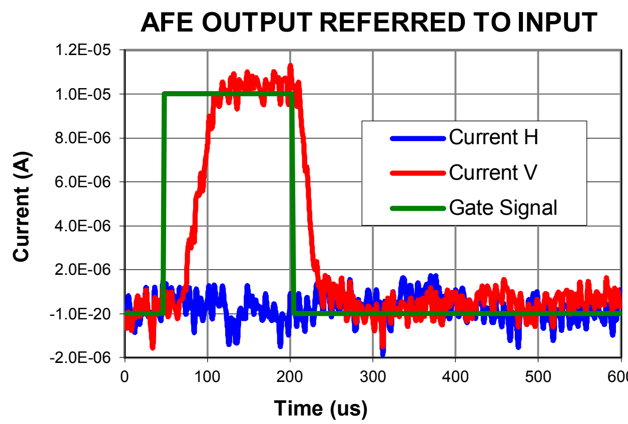

Figure 3: AFE X and Y wire currents.

The square pulse in Fig. 3 is the beam gate. The upper trace is the current collected by the vertical wire during a single macropulse. The LANSCE actuators include both X and Y wires on a single actuator with the wires configured to allow only a single wire in the beam at any time. The lower trace in Fig. 3 is the current collected by the horizontal wire while the vertical wire is being excited.

The vertical wire signal exhibits a noise level of nominally 1 µA RMS. In AFE systems comprising analog integration in the AFE, the effective noise bandwidth is reduced by the analog integration. Digital integration also results in a similar reduction in the noise bandwidth. Figure 4 shows the AFE analog output for a wire signal at the noise limit of the AFE, and the digital integration of this signal to obtain the actual charge collected at this current-signal level [4].

The integrated vertical wire current shown in Fig. 4 is identical to that which would be provided by an equivalent analog integrator integrating a single isolated pulse. Also, as expected of the integration, the noise is very substantially reduced. The noise-limited charge sensitivity is less than ~10 pC RMS.

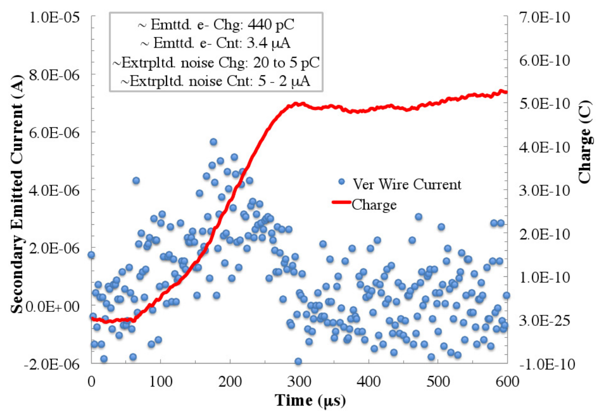

Figure 4: Noise-limited charge sensitivity.

As noted above, the advantage of the digital integration in combination with the wide-bandwidth AFE is that the currents collected from comparatively long macropulses at comparatively high pulse rate may be very accurately integrated without pulse pile-up error. Although the wide bandwidth of the AFE introduces noise in the current signal, the digital integration lowers the charge-equivalent noise in the same manner as an equivalent analog integration.

For the LANSCE wire scans, the wire is stepped sequentially through 80 X and Y positions across the beam to collect both the X and Y wire currents at each position. The current signals are digitized and integrated at each wire position to provide the charge collected at each position in the beam. Figure 5 shows all 160 digitally-integrated current signals of a single wire scan displayed in a single figure to show the resulting charge collected at each location.

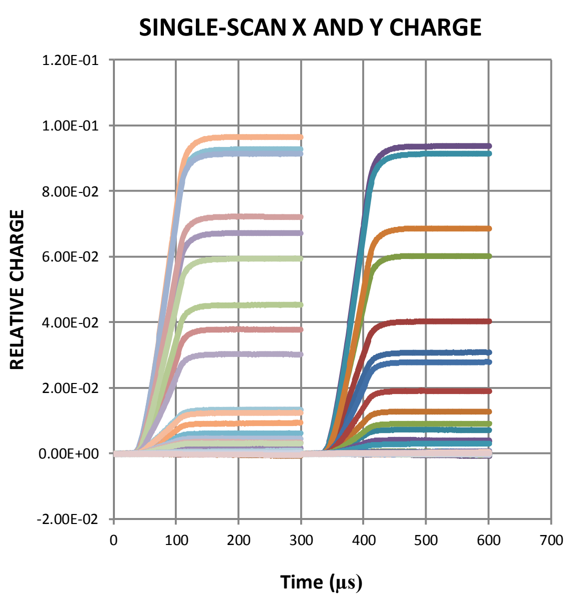

Figure 5: Single-scan X and Y charge.

Figure 5 shows the relative charge collected at each wire position from 80 successive macropulses in each axis. The data of Fig. 5 are combined in the wire-scanner system cRIO RT processor with the actuator position information collected at each sample position to create the spatial projected X and Y beam distributions. The projected distribution of the beam profile is shown in Fig. 6 [5].

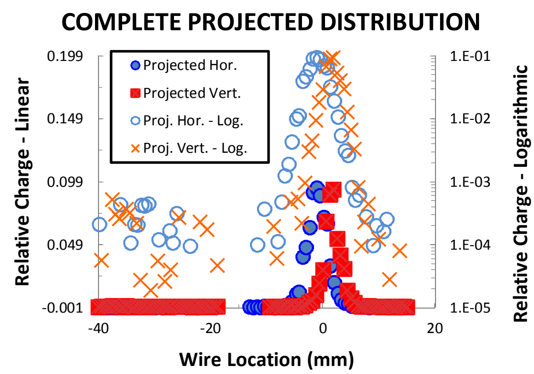

Figure 6: Complete X and Y distributions.

The results shown in Fig. 6 demonstrate that the application of a wide-bandwidth AFE and digital integration is quite effective in wire scans for collecting pulse-by-pulse wire current data to provide high-quality beam profile distributions even in applications where the beam duty cycle is too high for accurate analog integration.

CONCLUSIONS

The comparatively long 700 μs maximum macropulse and the 120 Hz maximum pulse repetition frequency of the LANSCE accelerator would result in substantial error in charge data if simple analog lossy integration were applied to integrate the wire-scanner wire-current signals. The use of a wide analog bandwidth in the AFE and digital integration allows collection of very accurate charge data, even at very high machine duty cycles, and provides the same noise-limited performance provided with analog integration.

REFERENCES

[1] L. J. Rybarcyk and F. E. Shelley, “Improvements to the LANSCE Accelerator Timing System,” PAC97, Vancouver, May 1997, 6P030, p. 2514 (1997); http://www.JACoW.org

[2] J. D. Gilpatrick et al., “Proposed Beam Position and Phase Measurements for the LANSCE LINAC,” DIPAC07, Venice, May 2007, TUPB10, p. 78 (2007); http://www.JACoW.org

[3] J. D. Gilpatrick et al., “Wire Scanner Beam Profile Measurements for the LANSCE Facility,” MOPPR081 these proceedings.

[4] J D. Gilpatrick et al., “Wire Scanner Beam Profile Measurements for the LANSCE Facility,” MOPPR080 these proceedings.

[5] J. Sedillo et al., “First Test Results of the New LANSCE Wire Scanner,” PAC11, New York, March 2011, MOP236, p. 554 (2011); http://www.JACoW.org