THE LANSCE LOW MOMENTUM BEAM MONITOR*

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Abstract

A diagnostic has been developed at the Los Alamos Neutron Science Center (LANSCE) for the purpose of identifying low momentum beam tails in the linear accelerator. These tails must be eliminated in order to maintain the transverse and longitudinal beam size. Instead of the currently used phosphor camera system, this instrument consists of a Multi Wire Proportional Chamber (MWPC) detector coupled to an EPICS compliant VME-based electronics package. Low momentum tails are detected with a resolution of 5 mm in the MWPC at a high dispersion point near a bending magnet. While phosphor is typically not sensitive in the nano amp range, the MWPC is sensitive down to about a pico amp. The electronics package processes the signals from each of the MWPC wires to generate an array of beam currents at each of the lower energies. The electronics has an analog front end with a high-speed analog to digital converter for each wire. Data from multiple wires are processed with an embedded digital signal processor and results placed in a set of VME registers. An EPICS application assembles the data from these VME registers into a display of beam current vs. beam energy (momentum) in the LANSCE control room.

ARCHITECTURE

The diagnostic is composed of a MWPC detector wired to a VME crate containing eight custom data acquisition and processing boards as shown in figure 1.

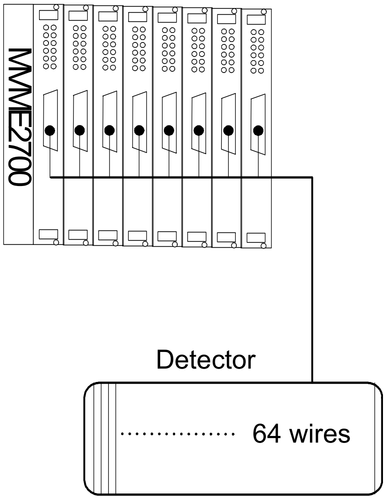

Figure 1: The 64 detector wires are supported by a remote VME crate with eight custom processing boards and a Motorola MVME2700 processor.

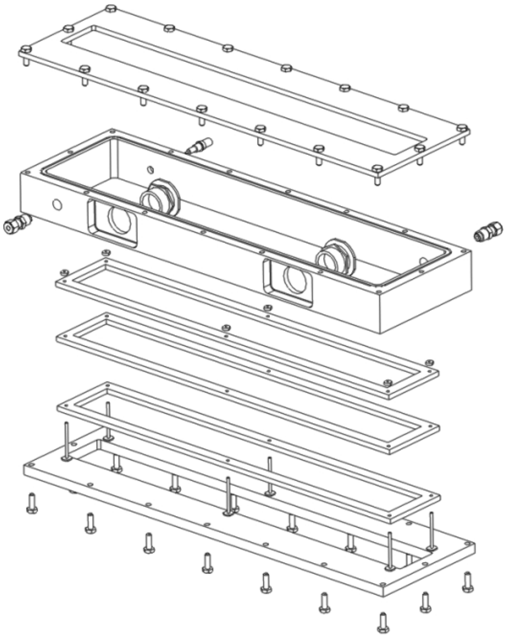

Figure 2: Solid Model drawing of detector assembly.

The detector is gas filled and contains 64 wires. The electronics supports them with 64 individual parallel processing channels in the VME crate.

There are cables containing 64 individual twisted pairs running from the detector to the VME crate. Each custom VME board handles eight of the 64 detector wires. The detector is located in the LANSCE beam tunnel just down stream and inboard from the XDBM04 bending magnet.

800 MeV beam entering this magnet is bent toward the experimental areas. Beam components at lower energies, however, are bent in a tighter radius and hit an inboard beam stop. These are the low energy components that should be eliminated. The detector is placed between this bending magnet and the beam stop so it can measure the magnitude spectrum of beam currents over a range of unwanted low energies [1].

MULTIWIRE CHAMBER

The chamber contains 64 gold plated tungsten wires that are stretched across a fiberglass frame. The wires are 5 mm apart and sit between two high voltage plates. The high voltage plates are made of 25 μm aluminum foil also supported by fiberglass frames. The area inside the frames is 50 cm x 6 cm or 300 square cm. The wires and high

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voltage plates are housed in an aluminum enclosure with hermetic gas, high voltage, and signal connectors. The enclosure is filled with a 10% methane – 90% argon gas mixture. A 100 μm thick aluminum foil window allows beam to enter the enclosure [2].

When a particle traverses the detector, it produces electrons by ionization, which are then multiplied by the strong electric field around the wire. The gain of the detector increases with the amount voltage on the foil plates. The current multiplication factor, M, for this multiwire chamber is given by equation (1) below [3].

$$M = \exp\left[2\sqrt{\frac{akNCVo}{2\pi\varepsilon_o}}\left(\sqrt{\frac{Vo}{Vt}}-1\right)\right] \qquad (1)$$

Where $k = 1.81\times10^{-17}\text{cm}^2/\text{V}$, which the Townsend constant, N is the number of molecules per unit volume, C is the capacitance between the wire and the plate, ε_0 is 8.85pF/m, and a is the radius of the wire. Vo is the voltage on the foil and V_t is the threshold voltage, which is 1500 volts in this case.

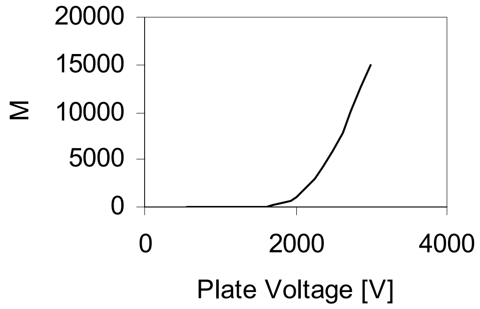

Figure 3: The multiplication factor, M, plotted as a function of plate voltage.

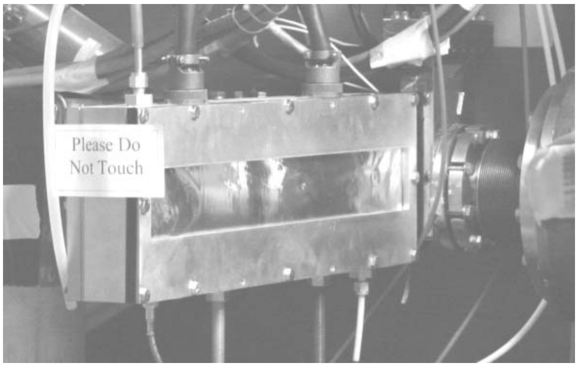

Figure 4: The detector in place in the LANSCE switchyard beam tunnel.

The multiplication factor is plotted vs. plate voltage in figure 3. At 3kV, the multiplication factor is 1.5×10^4.

SIGNAL

When a particle traverses the detector wire a fast current pulse is produced. The simplest processing method is to count these pulses and the electronics have been designed to do this in addition to a more sophisticated integration technique. Integration of the pulses is preferred because the bandwidth of the cable plant is slow compared to the raw pulses, which causes pile-up. Once that happens, individual pulses can no longer be separately counted.

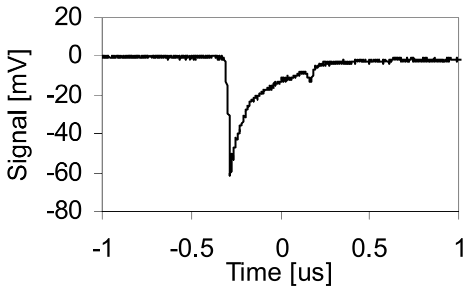

Figure 5: Raw pulse from detector wire showing pile-up problem.

A typical pulse from a detector wire is shown above in figure 5. The pile-up problem can be observed with a -20 mV pulse partially absorbed into the –60 mV pulse that preceded it. Integrating, on the other hand, allows us to calculate the rate at which charge is collected on each detector wire.

DIGITAL SIGNAL PROCESSING

Each detector wire has its own signal conditioning electronics, analog to digital converter (ADC), and field programmable gate array (FPGA) for digital signal processing [4]. Furthermore, there is a dedicated digital signal processor for every eight wires used to perform floating-point math. Frequency analysis of the input signal has shown that there are no significant components above 1.5 MHz [1]. The signal is then bandwidth limited to 5 MHz by an analog signal conditioner and digitized at 10 MHz. The FPGA processes the digitized data at the full 10 MHz.

The gate for this integration is generated internally by the FPGA based on a trigger pulse from the LANSCE master timer [5]. Gates at LANSCE are not longer than 1 ms and the hardware supports programmable gates up to 6.5 ms. Integrals have to be calculated at the LANSCE beam repetition rate, which is 120 Hz.

The integral, equation (2), is formed partially in the FPGA and then completed in the DSP as shown by the signal processing block diagram in figure 6. In equation (2), and in figure 6, n is the sample number within the integration gate, x_n is the digitized sample, T is the sample time, 1 / 10 MHz, and y_n is the integrated output.

The FPGA uses an accumulator-based technique to form a partial integral using fixed-point math. It can do this in real time at the full rate of the ADC.

$$y_n = T\left[\frac{1}{2}\left[x_0 + x_n\right] + \sum_{i=0}^{n-1} x_i\right] \qquad (2)$$

The FPGA collects the first sample, x_0, the last sample, x_n, and accumulates all the samples in between. It then hands this information off to the DSP at 120 Hz to form the complete integral using floating-point math. The result is further processed by the DSP with a six pole low pass filter before being delivered to the EPICS control system for display in the LANSCE central control room [6].

A block diagram of the process is shown in figure 6. A 14-bit digital signal flows into the left side of the block diagram and is processed by the FPGA. Inside the FPGA, the timing hardware selects the first and last sample inside the integration gate and stores them in the registers marked x_0, and x_n, respectively. It accumulates the samples in between, x_1 and x_{n-1}. The analog and digital electronics are bipolar and the accumulator can accommodate both negative and positive values in real time using two's complement math. The FPGA operates at 10 MHz while the integration gate is open, then stops and holds its values when the gate closes. The floating point DSP on each VME board then reads the x_0, x_n, and $\Sigma(x_n)$ values for further processing. This method allows for complete processing of the signal inside the VME crate. Only low bandwidth results need to be sent over the network. The resulting spectrum may be displayed directly on an EPICS screen.

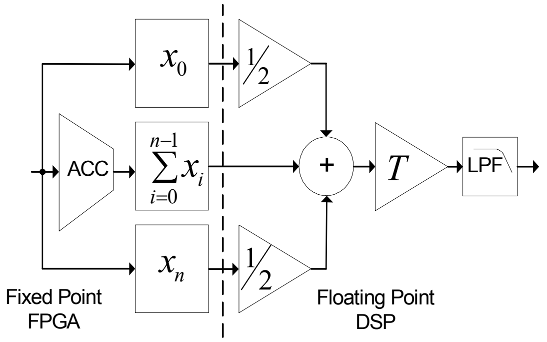

Figure 6: Signal processing block diagram.

MEASUREMENT

A first order measurement with this detector has been performed using a cobalt-60 source. With the source placed about 2 cm from the detector an end-to-end measurement was made. The spectrum measured with the source in front of wire #16 is shown in figure 7. For this measurement, only the first 40 of the full set of 64 wires were used.

The graph shows that the detector, electronics, and cable plant can process low energy beam components down to less than 20 pA or around 10,000 particles per wire.

FUTURE

Now that the detector is installed and the electronics have been tested, we are looking forward to tuning the LANSCE linear accelerator with the aid of this new diagnostic.

In practice, all 64 wires will be used and the x-axis will be relabeled for the beam energy each wire corresponds to 350 MeV to 750 MeV.

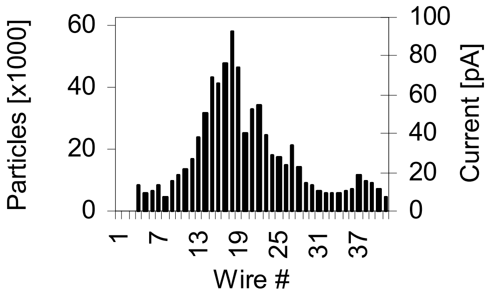

Figure 7: Measured spectrum using a Cobalt-60 source.

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