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A FAST, WIRE-PLANE PROFILE MONITOR FOR EXTRACTED PROTON BEAMS*

J. R. SIMANTON and R. F. MARQUARDT

High Energy Facilities Division, Argonne National Laboratory, Argonne, Illinois, U.S.A.

and

F. HORNSTRA, Jr.

Accelerator Division, Argonne National Laboratory, Argonne, Illinois, U.S.A.

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Wire planes, operating in air as ionization collectors, have been instrumented to provide continuous and essentially instantaneous readout of extracted proton beam profiles at the Zero Gradient Synchrotron. The value of the profile monitor as a diagnostic tool and as input for computer optimization of beam on external targets is illustrated and discussed.

1. Introduction

Manually-scanned wire-planes, operating in air as ion current collectors, have been used since early 1968 as high-resolution, non-destructive profile monitors for extracted proton beams of the Zero Gradient Synchrotron (ZGS)[1]. Electronically-scanned, these devices now provide continuous and essentially instantaneous readout.

Since the wire planes have been described in the earlier paper, the emphasis in what follows will be on the instrumentation and its performance.

In its present form, 16 time-sequenced profiles are scanned during a single beam spill, starting at a preselected time. The individual 48-element profiles may be integrated over an arbitrary number of beam spills. The speed of the device permits observation of profiles as a function of beam spill time, providing accelerator operators with a convenient diagnostic tool and high resolution data input for computer optimization of beam spot size, position, and intensity on external targets.

2. Description

Fig. 1 is a block diagram of the readout system. The beam passes through perpendicular to a parallel array of forty-eight 0.025 mm diameter aluminum wires on

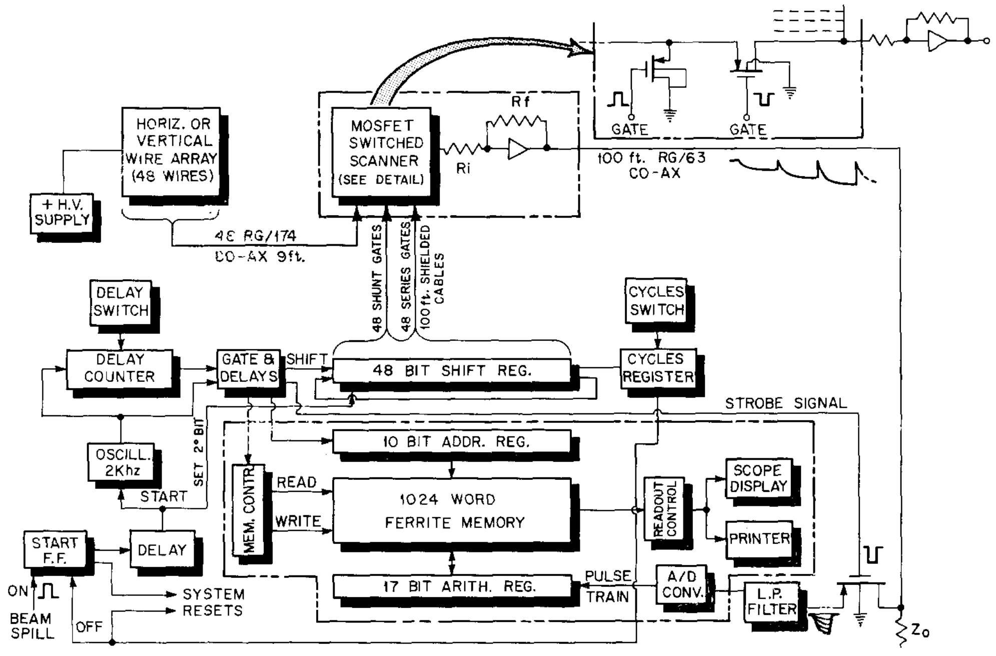

Fig. 1. Profilometer block diagram.

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1 mm centers. During readout, the wires are individually disconnected from ground and connected to the operational amplifier input, in sequence. Wire selection is accomplished by a MOSFET switched multiplexer, sequenced by a shift register. The amplifier output level is strobed by a series MOSFET switch with the resulting pulse presented as input to an analog-to-digital converter via a low-pass filter to remove switching transients. The output of the A/D converter is a pulse train, which is counted serially into the 17-bit binary arithmetic register, then parallel transferred into a 1 024-word ferrite memory. Data in the memory can be displayed or printed out non-destructively.

Scanning is initiated by a ZGS START signal which slightly precedes beam spill. The time elapse until the first wire is sampled is determined by presetting a delay counter. After all 48 wire currents have been sampled once, scanning either ceases or is repeated in accordance with the presetting of the cycles counter. Each cycle represents a complete 48 wire profile scan. Up to 16 profiles may be scanned during one beam spill. To eliminate random beam structure, profiles may be integrated over an arbitrary number of beam spills, in which case each wire is always sampled at the same times relative to start of beam spill; the previous count accumulation is parallel transferred from memory into the arithmetic register, incremented by the new sample count, then rewritten at the same memory address.

3. Construction

The A/D converter, memory, and display elements within the dashed enclosure (at bottom of fig. 1) are a modified commercial pulse height analyzer. Modification is sufficiently minor that two added manual switches convert the analyzer from conventional pulse height operation to its profilometer mode.

The other dashed enclosure (top of fig. 1) contains 96 MOSFET switches (connected as shown in the adjacent detail) and an inexpensive FET input operational amplifier, all mounted on a single 12″ × 12″ card in a shielded box. The remaining logic is conventional. The separation of approximately 100 ft between the scanner and associated electronics could be increased manyfold, since the signal cable is terminated, the signals are relatively slow, and gate cable capacity does not determine rise times.

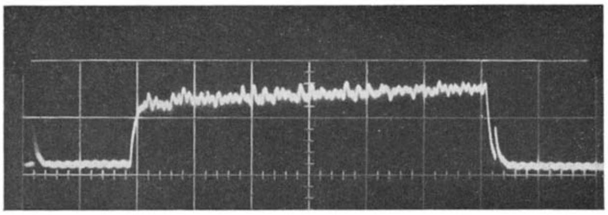
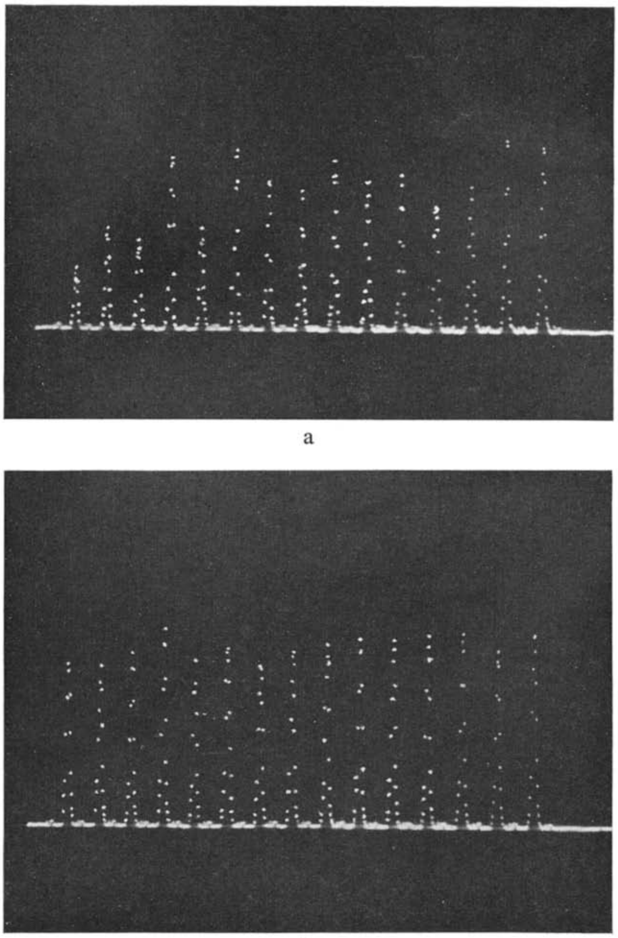


Fig. 2. Typical ZGS proton beam spill.



a

b

Fig. 3. Time-sequenced beam profiles (early scan). a. Displayed after a single beam spill; b. Displayed after integrating 20 beam spills.

The time constant (≈ 30 μsec) for a selected wire is determined by the approximately 300 pF capacitance (represented by 9 ft of RG174 cable) and the 100 kΩ input resistor of the amplifier; both could be reduced for faster operation if desired. With the 2 kHz oscillator frequency, 500 μsec (≈ 17 time constants) are available to reach equilibrium current level.

The level is strobed for 4 μsec just prior to switching to the next wire. Analog-to-digital conversion proceeds concurrently with charging of the next selected wire. By shortening the input time constant and strobe duration, the oscillator frequency could be increased and profile scan time decreased by perhaps two orders of magnitude without great difficulty. However, at least for our application, the 30 μsec input time constant provides a degree of smoothing of structure superimposed on the beam spill. We prefer a relatively slow (2 kHz) scan rate so that the 16 time-spaced profiles cover a reasonable fraction (384 msec) of a typical 600 msec spill. By scanning only 32 wires, we could store 32 profiles per spill within our memory capacity. However, we have found 16 to be a maximum for convenient visual observation.

4. Results

Fig. 2 shows structure superimposed on a typical 600 msec ZGS beam spill, as monitored by a conventional ionization chamber.

Fig. 3a shows 16 time-sequenced horizontal profile scans, measured with the system of fig. 1 during a single typical beam spill of approximately 2×10^{11} protons. The horizontal spacing between dots represents 500 μsec; a complete profile of 48 dots requires 24 msec. Each dot represents one of 48 wires spaced on 1 mm centers. The ordinate at each dot represents the relative ionization current flowing in that wire at the instant it is strobed. In both figs. 3a and 3b the scan begins before the start of beam spill; hence, the first profile is missing. Fig. 3b conditions are identical to those of fig. 3a except that the profiles have been integrated in memory for 20 consecutive beam spills (requiring about one minute) before scope display. The improvement in profile uniformity demonstrates the elimination of random spill structure by integration. The higher peaks in fig. 3a represent about 600 digitized counts. Peaks in fig. 3b contain about 10 000 counts. A known voltage was imposed on a few wires well away from beam center, as a check on amplifier offset drift, noise level, gain, and scan position. These appear in all photos. The flat base line which immediately precedes and follows each main profile represents 0 counts and indicates a negligible noise level for this beam intensity.

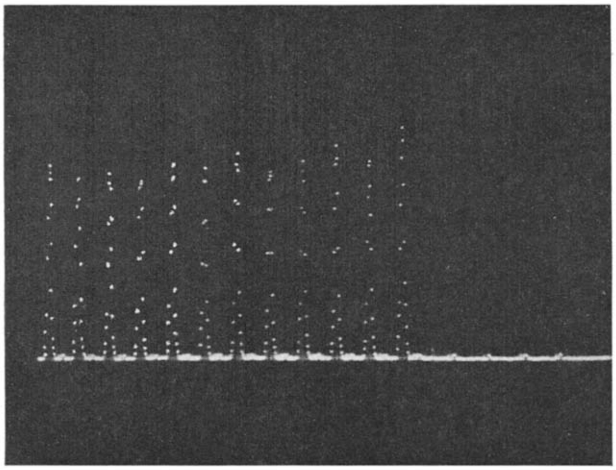


Fig. 4. Time-sequenced beam profiles (late scan); displayed after integrating 20 beam spills.

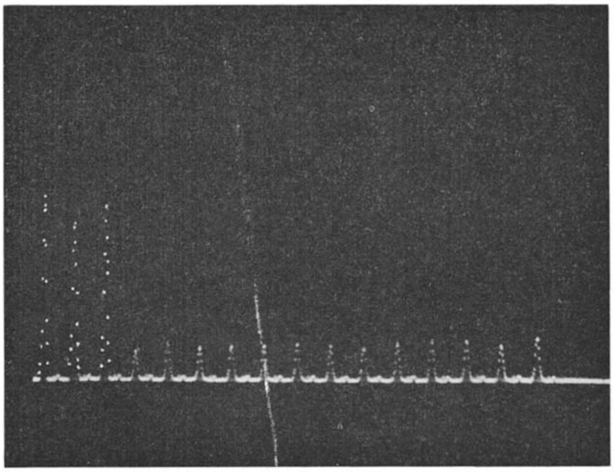


Fig. 5. Time-sequenced beam profiles showing an abrupt intensity reduction during spill; displayed after a 20 spill integration.

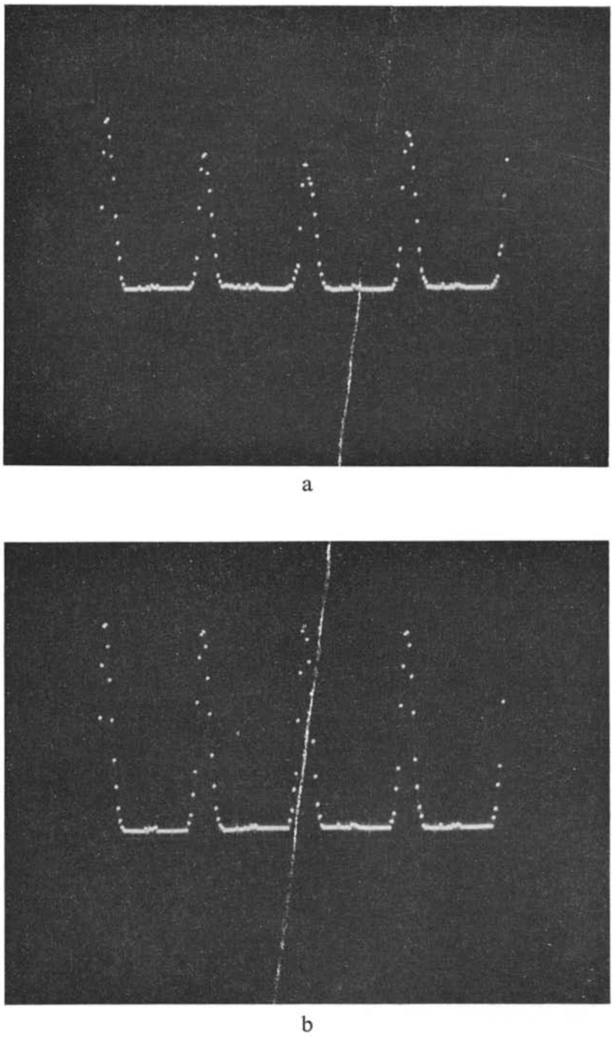
Fig. 4 is similar to fig. 3b except that sampling has been preset sufficiently late that beam is missing for the final few scans.

Fig. 5 is a 20-spill integration showing an abrupt reduction of beam intensity in midrange of beam spill.

Fig. 6a displays expanded baseline profiles occurring during a single beam spill. For comparison, fig. 6b displays expanded profiles from a 20-spill accumulation. The improvement with integration is again apparent, as is the ease with which beam width at half maximum (fwhm) in millimeter is determined by counting dots in the upper half of a profile. Spot position shifts too minute for visual observation are readily detected by the wire-by-wire memory printout.

5. Discussion and future plans

In our earlier paper we compared manually-scanned, wire-plane profiles with simultaneous but independent results obtained using the tedious, and operationally complex, scatter target/scintillation telescope technique generally employed by high energy physicists at the ZGS. The excellent agreement encouraged construction of the present scanning system. Profiles obtained with the fast scan have been compared with concurrent manual scans. Rapid-scanned profiles tend to yield narrower profiles, as one might expect, since manual scans consume about $\frac{1}{2}$ h, during which changes in in-



a

b

Fig. 6. Profiles displayed with scope baseline expanded. a. A portion of a 16-profile single beam spill; b. A portion of 20 consecutive beam spills after digital integration in memory.

tensity, position, and spot size all contribute to the fwhm determination.

Sequential scanning with digital integration was chosen for our first interface, rather than the alternative method of sampling all wires simultaneously. Sequential scanning is particularly adapted for fast beam diagnostics, whereas the latter method is subject to charging and holding errors when sampling times are short. Digital integration is versatile and can be employed to whatever degree the investigator desires to reduce random structure. Repetitive structure effects can be studied by shifting scan start relative to beam spill. An important design consideration was to demonstrate that a slightly modified commercial pulse height analyzer can perform most of the readout functions. This was important because many ZGS experimenters consider it crucial to know the precise beam conditions at their targets. Since pulse height analyzers are commonly used in accelerator experiments, they provide a convenient instrument for local monitoring. Modest alteration of the sequencing logic yields alternate horizontal and vertical profiles – or two-dimensional, intensity-modulated spot size displays, if a two parameter pulse height analyzer is available.

To date the system has performed with beam intensities ranging from about 1×10^{10} to 3×10^{11} protons/sec. Robust signals and low noise levels indicate that good operation should prevail for at least one decade lower intensity levels. In principle, much lower intensity profiles can be achieved at the expense of high speed diagnostic capability. At low levels, the wire planes must operate as controlled gas-flow ionization chambers; individual wire currents simultaneously charge high-quality, precision capacitors, which hold their charge till scanned. One such interface has been constructed and will be evaluated for low intensity beams.

We are currently operating wire planes in the proportional mode to extend their range downward for secondary beam coverage. Instrumentation is being prepared for a fast, position-sensitive event trigger for bubble chamber application. It is conceivable that proportional and ionization mode wire planes, with suitable interfacing, will soon non-destructively profile minimum ionizing beams over all ranges up to 10^{13} particles/sec.

6. Conclusion

We have developed a fast, simple, versatile, high-resolution, non-destructive profile and position monitor for use in extracted proton beams of the ZGS. It is rapidly replacing older methods used by ZGS machine operators and experimental groups. In the near future, scanning, display-generation, and beam spill and spot size optimization will be accomplished under ZGS computer control.

We wish to thank R. Scherr for mounting and installing the wire planes and providing independent manual scans for comparative evaluations.

Reference

[1]) F. Hornstra, Jr. and J. R. Simanton, Nucl. Instr. and Meth. **68** (1969) 138.