BEAM MANIPULATION EQUIPMENT AT THE ZERO GRADIENT SYNCHROTRON*

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Summary

The evolution of working accelerators invariably requires increasingly flexible beam manipulation to fulfill the demands of high energy physics experiments. The following reports on a hybrid digital-analog system that provides intricate beam manipulation programs for use with the Argonne Zero Gradient Synchrotron (ZGS). It describes the system requirements, the design philosophy, the equipment developed to fulfill these requirements, and finally, the present performance of this equipment. Figure 4 shows one view of the completed system.

System Requirements

There are five major requirements to be met in any system designed to provide the flexibility and control necessary in developing ZGS targeting programs.

1. The system must provide an adjustable analog waveform compatible with the ZGS master oscillator. The system output must be reproducible to within 10 mV and noise must be held to less than 3 mV. Higher noise levels may lead to beam losses throughout the entire acceleration process. Signals of $\pm$ 10 V are necessary to allow the accelerated beam to be moved to both inner and outer vacuum chamber walls.

2. Compatibility with the ZGS programmer is also a requirement.[1] The timing pulses available from the programmer lead to a pulse controlled and synchronized waveform generator.

3. Constant rate spills up to 500 ms in length are common slow spill requirements for high energy physics experiments at the ZGS. The system designed must then be part of a closed-loop between the targeted beam and the master oscillator. Targeted beam information is available from photomultipliers located near the target area straight section of the ZGS.

4. In the case of bubble chamber experiments, short (less than 2 ms) RF beam spills are often used. To provide uniform chamber pictures, it is desirable to limit the number of particles transported to the chamber. To fulfill this requirement, the generated analog waveform must be able to be stopped, started, or in some selectable way be modified by an incoming pulse; e. g., a pulse that is derived from a particle count to a bubble chamber could be used to cause the removal of the proton beam from a target.

5. The ease with which the targeting programs can be set up and adjusted required readily accessible analog controls. This allows the operator to adjust the generated waveform by a combination of dial controls. There are a large number of subtle decisions to be made in obtaining high quality beam spills in the shortest possible time. This fact leads directly to the use of a human operator (capable of making such decisions) as the feedback element between obtained beam spill and the proton beam position controller. Wideband radial position changes are obtained by analog techniques as discussed in (3) above.

Design Philosophy

To fulfill the above requirements, the system of Fig. 1 was developed. The decision was made to design the system such that analog signals be obtained from pulses of adjustable amplitude and polarity. Though this leads to a generated waveform comprised of straight line segments, the problem of noise and stability was confined to only a few operational amplifiers. It also allowed the use of logic techniques to provide the flexibility of operation desired. Furthermore, the quality obtainable in commercially available integrated circuits permitted their use throughout the system.

The system in its simplest form consists of a n-bit binary counter that can be advanced or set to any value by incoming pulses. Each state of the counter is then decoded into one line for each counter state. Each line, in turn, drives an amplifier (level gate) that, when selected, provides as an output a precise voltage level. The output of each level gate is then divided into two channels labeled $\dot{X}$ and X_{limit}, where $\dot{X} = dX/dt$. X at the ZGS is the defined coordinate for radial beam position. $\dot{X}$ and X_{limit} can then be modified separately in amplitude and polarity. The $\dot{X}$ level is then integrated and applied to one input of a voltage comparator with X_{limit} being applied to the other.

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When equality of the waveforms is reached, the voltage comparator generates a pulse that advances the counter. The integrated $\dot{X}$ level is used as the output of the system and the input to the master oscillator. Thus, each state of the counter represents a breakpoint or straight line segment of adjustable slope ($\dot{X}$) and length (X_{limit}).

This process continues until the counter is recycled to its rest state. Figure 5 shows an arbitrary waveform obtainable from the system. Note that the X_{limit} can be either positive or negative regardless of the sign of $\dot{X}$.

System Design

In reality, the system consists of two 3-bit binary counters that can function separately or sequentially depending upon the mode selection, see Figs. 1 and 3. The output is either two separate waveforms of seven breakpoints each or one waveform of fourteen breakpoints.

The system is best described by a discussion of each function on the front panel, see Fig. 3.

$\dot{X}$ and X_{limit} Controls

As discussed above, the output of the level gate is divided into the $\dot{X}$ and X_{limit} channels. The modification in amplitude and polarity of each of the channels is accomplished by using the potentiometers to vary amplitudes and the toggle switches, in conjunction with inverting amplifiers, to control polarity. Figure 2 shows a simplified schematic of the scheme used.

10 X

The 10 X pushbutton provides an order of magnitude greater slope by the push of a button. The voltage limit is not altered. Functionally, this is obtained by a 10 X gain change in the $\dot{X}$ amplifiers.

Beam Feedback

Referring to Fig. 1, an enabled beam feedback pushbutton permits targeted beam spill information, obtained from a group of photomultipliers , to be added algebraically to the $\dot{X}$ pulse at the input to the $\dot{X}$ integrator. The spill information is automatically modified by the sign of $\dot{X}$ so as to always provide negative feedback. Since the gain of the targeted beam signal is fixed for any single mode of targeting, the rate at which beam is targeted is dependent only upon $\dot{X}$. This allows constant rate long beam spills as shown in Fig. 6. The beam spill can be terminated by advancing the counter to a different breakpoint adjusted so as to move the beam off the target. Slow proton extraction is also possible when the ZGS Piccioni extraction scheme is used.

Preset

The preset pushbutton allows direct access to the counter. An incoming preset pulse sets the counters to the breakpoint at which the preset button is depressed. This allows the counter, and ultimately the system output, to be started, stopped, or recycled in any desired manner by appropriate time placement of incoming preset pulses.

Constant Spill Time

Referring to Fig. 2, it can be seen that by enabling the constant spill time (CST) pushbutton, the $\dot{X}$ pulse amplitude is made a function of the accelerated charge in the ZGS. When this charge dependent $\dot{X}$ pulse is algebraically added to the beam spill signal, the result is a waveform that generates a fixed length spill for every ZGS cycle. The rate will, however, be charge dependent.

Multiple spills are easily obtained by judicious use of the available system functions and appropriate use of the timing pulses from the ZGS programmer. Figure 8 is an example of a multiple beam spill targeting program, the first being a short bubble chamber beam spill and the second a 500 ms beam spill.

Present System Performance

Though the system has only recently been completed, it has demonstrated its flexibility during high energy physics experiments. Figure 6 is a photograph of a long (500 ms) beam spill using spill feedback. Figure 7 shows a short spill typical of bubble chamber experiments. Figure 8 is a photograph of a simple multiple spill program.

Though no significant reliability data has been obtained, of the 150 integrated circuits used, no failures have occurred.

I would like to express my appreciation to N. R. Wilson, R. L. Biwer, G. E. Huff, R. S. Konecny, J. L. Murphy, D. M. Pansegrau, and V. D. Sager, without whose dedicated efforts the system described would not have been possible. Recognition must also be made to J. A. Dinkle who provided the initial targeted beam manipulation equipment in use at the ZGS and from which many ideas were incorporated.

Reference

1. L. G. Lewis, "Computer Control of High Energy Accelerators", IEEE Transactions on Nuclear Science, Vol. NS-12, No. 3, June 1965.

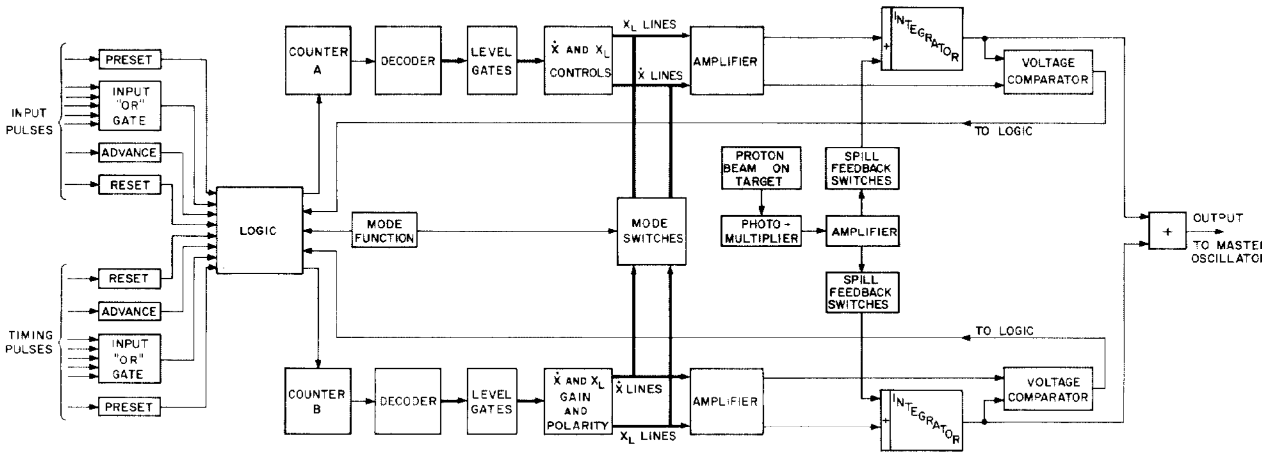

Fig. 1 System Block Diagram

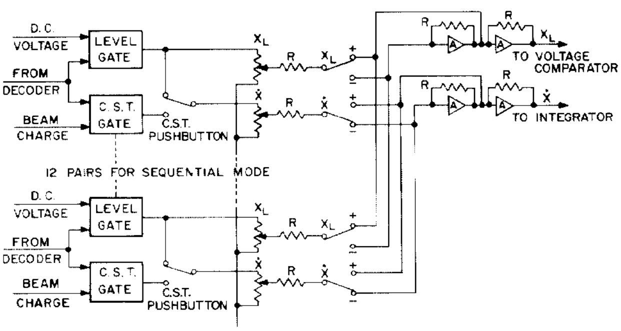

Fig. 2 $\dot{X}$ and X_{limit} Controls Schematic

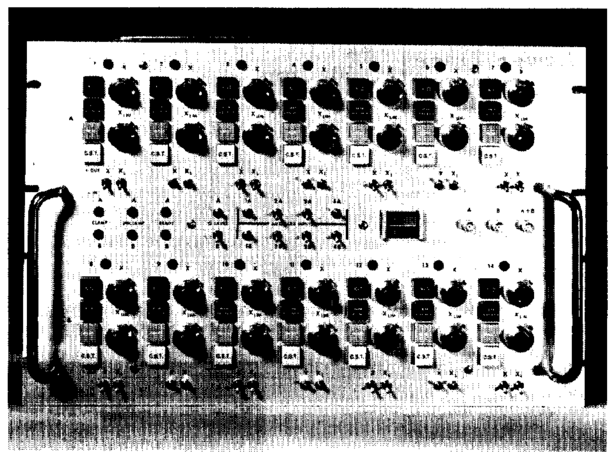

Fig. 3 Front Panel

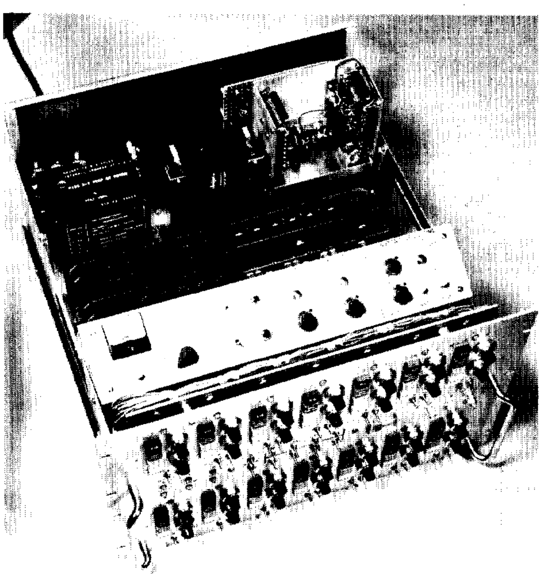

Fig. 4 Top View

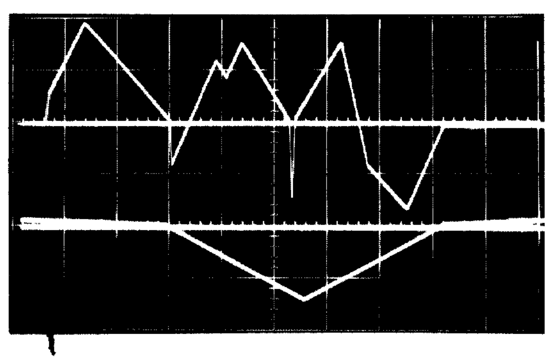

Fig. 5 Arbitrary System Output

	Vertical Sensitivity	Horizontal
Upper Trace	5 V/cm	100 ms/cm
Lower Trace	5 V/cm	2 ms/cm

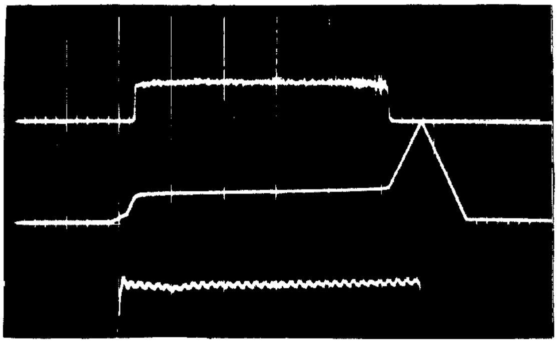

Fig. 6 Slow Spill

	Vertical	Horizontal
Upper Trace	Photomultiplier Output	100 ms/cm
Middle Trace	System Output 5 V/cm	100 ms/cm
Lower Trace	Magnetic Field B 50 g/cm	100 ms/cm

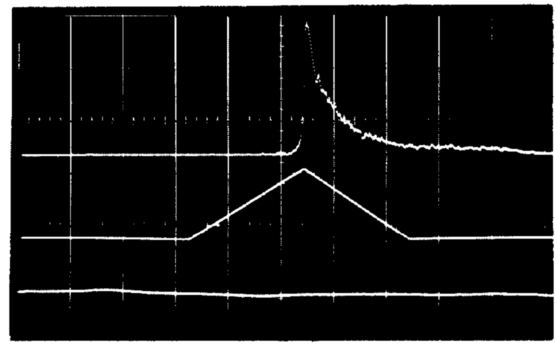

Fig. 7 Bubble Chamber Spill

	Vertical	Horizontal
Upper Trace	Normalized Photomultiplier Output	1 ms/cm
Middle Trace	System Output 2 V/cm	1 ms/cm
Lower Trace	Magnetic Field B 50g/cm	1 ms/cm

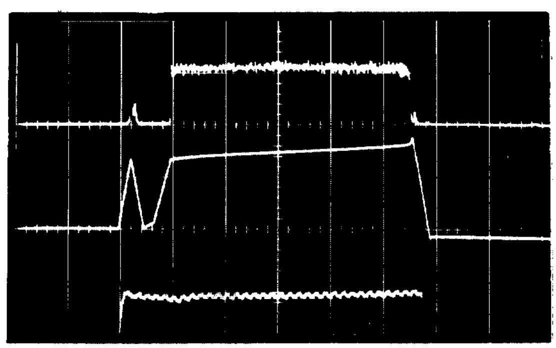

Fig. 8 Multiple Spills

	Vertical	Horizontal
Upper Trace	Normalized Photomultiplier Output	100 ms/cm
Middle Trace	System Output 2 V/cm	100 ms/cm
Lower Trace	Magnetic Field B 50g/cm	100 ms/cm