A SYNCHRONOUS BEAM SWEEPER FOR HEAVY IONS

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Abstract

The Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory provides a wide range of accelerated heavy ions from the periodic table. Frequently, the beam delivery rate of 12 MHz is too fast for the type of experiment on line. Reaction by-products from a target bombardment may have a decay interval much longer than the dead time between beam bunches. To prevent data from being corrupted by incoming ions a beam sweeper was developed which synchronously eliminates selected beam bunches to suit experimental needs. As the SWEEPER is broad band (DC to 4 MHz) beam delivery rates can be instantaneously changed. Ion beam bunches are selectively kicked out by an electrostatic dipole electrode pulsed to 2 kVDC. The system has been used for almost three years with several hundred hours of operating time logged to date. Beam bunch delivery rates of 6 MHz down to 25 kHz have been provided. Since this is a non-resonant system any beam delivery rate from 6 MHz down to zero can be set. In addition, burst modes have been used where beam is supplied in 12 MHz bursts and then shut down for a period of time set by the user.

Beam Pulse Removal Technique

The ATLAS accelerator system is synchronized from a master clock operating at 12.125 MHz. All accelerating structures are synchronized to this clock and therefore are harmonically related. Accelerated ions arrive at a rate of 12.125 MHz and typically have a bunch width of 1.0×10^{-9} second at the beam sweeper station. The beam sweeper is located between an FN Tandem Van de Graaf injector and the superconducting linac of ATLAS. Typically, the ions have an energy of ~ 1.5 MeV per nucleon in this region. We use electrostatic fields to synchronously DEFLECT selected ion bunches onto a pair of vertical slits located a short distance downstream of the beam sweeper. The non-deflected ion bunches continue on through to be accelerated to higher energies. Voltage pulses on the deflection electrode are synchronized to the master clock, therefore rise and fall times must be less than one clock period. This is necessary to avoid unwanted vertical forces on the beam bunches selected for further acceleration. The sweeper must drive the deflection electrode to sufficient voltage for all species of ions and various charge states. The amount of ion deflection is a function of many factors as shown below:

$$\Delta Y = \frac{L Q_s V_p \ell_e}{S(Q_T+1)V_T} \qquad (1)$$

where: ΔY = vertical displacement of beam bunch at vertical slits (meters)

L = drift distance to vertical slits (meters) 2.06 M

Q_s = charge state of ions within deflecting electrode 5

V_p = deflecting potential (volts) 1000

ℓ_e = deflecting electrode length in meters 0.5

S = deflecting electrode plate spacing in meters 0.025

Q_T = charge state ions out of FN tandem accelerator 5

V_T = FN tandem accelerating voltage (volts) 8.5×10^6.

For example, consider a beam of $^{12}C^{+5}$ at 51 MeV. If the deflection electrode is pulsed to 1000 V beam bunches will be vertically displaced by 5.2 mm at the slits. The slits would be adjusted to stop deflected beam but pass non-deflected bunches. Figure 1 shows the timing relationship necessary to eliminate two out of three 12.125 MHz beam bunches. The most difficult task in designing the beam sweeper was the vacuum tube output stage. Cascoded triode vacuum tubes were used where one tube charges the deflection electrode in 50 nsec and the other tube discharges the electrode in 50 nsec. Figure 2 shows a simplified schematic of the system; a more detailed discussion of the output stage will follow.

Electronic System Outline

As Fig. 2 shows, the master clock frequency is divided down and used to program the beam sweeper driver stages. The master clock programmer divides the 12.125 MHz clock according to how two banks of thumbwheel switches are set. One bank sets the number of beam bunches to be transmitted, and the other one sets the number of clock periods desired per bunch transmission interval. The clock pulse conditioner corrects for drive-pulse width errors that would appear at the deflection electrode. These errors are due to various turn-on delays, and pulse stretching due to stored charge effects, inherent to the various solid-state devices in the sweeper driver stages. The interlock system provides equipment and personnel safety during operation. A digital programmer is used to generate the various pulses necessary for synchronized operation of both vacuum tube output stages. There are two separate intermediate driver stages. One drives vacuum tube switch V_1, and the other drives vacuum switch V_2.

Sweeper Output Stage

Microwave planar triodes (8940) were selected to drive the deflection electrode because of their low parasitic capacitance, unique plate current characteristics, and modest grid drive requirements. Although these vacuum tubes have high peak plate current capability, their average grid dissipation is low. For this reason considerable effort was made to reduce stray capacitance in the system. The deflection electrode capacitance and associated stray capacitance due to the vacuum tubes,

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transformers, and mechanical mounting all add together. The total capacitive load must be driven to 1 kV or more, and then discharged in less than 100 nsec. This must be done at frequencies up to 4.0 MHz in our present configuration. The planar triodes control grid dissipation is limited to 2.0 watts average power. This limit is easily exceeded when operating at high switching frequencies, so load capacitance must be minimized. To charge a given load capacitance in a short interval of time requires a specific amount of vacuum tube plate current.

$$I = \frac{C\Delta V}{T} \qquad (2)$$

where: ΔV = voltage change across the load in volts (1000V)

C = load capacitance in farads (7.15×10^{-11} F)

T = charging time in seconds (5×10^{-8} sec)

I = Vacuum tube plate current in amperes.

In our beam sweeper, charging the deflection electrode to 1000 V in 50 nsec required 1.43 amperes of plate current from tube V_1. To discharge this energy vacuum tube V_2 must sink the same amount of current in 50 nsec or less. Considerable effort was made in reducing all capacitances that contribute to the total load.

The various load capacitances are shown below:

V_1 filament transformer capacitance = 6.5 pf

V_1 grid drive transformer capacitance = 6.5 pf

V_1 plate to cathode capacitance = 10.0 pf

V_1 mounting capacitance = 10.5 pf

V_2 plate to cathode capacitance = 10.0 pf

Beam deflection electrode capacitance = 28.0 pf

Total load capacitance = 71.5 pf

Referring to Fig. 2, tube V_1 charges the deflection electrode to a specified level and tube V_2 discharges it. Vacuum tube V_2 must be held in a cut-off condition during V_1 conduction and remain cut-off until needed to discharge the electrode. The grid drive signal for tube V_2 is a composite of two signals. First, when the electrode must be discharged, a positive going grid drive pulse of short duration is used to drive V_2 into sufficient conduction. After that, V_2 grid bias is maintained at zero volts for as long as needed. Just before tube V_1 is turned on, the grid bias on V_2 is driven to a cut-off level. The composite grid drive signal for V_2 is shown in Fig. 2 along with other related signals.

Both grid drivers use field effect transistors because these devices have low "on" resistance and are relatively easy to drive. The vacuum tubes are used in a common cathode configuration which means that Miller effect must be dealt with. As you know, Miller effect is the apparent multiplication of triode tube input capacitance due to grid-to-plate coupling and voltage gain μ.

$$C_{IN} = C_{GK} + C_{GP}\,(1 + \mu) \qquad (3)$$

where: C_{IN} = input capacitance modified by Miller effect

C_{GK} = grid to cathode capacitance

C_{GP} = grid to plate capacitance

μ = control grid voltage gain with respect to plate (with plate current constant).

For the tubes used, the Miller effect input capacitance is about 900 pf. The result of this phenomenon is that fast control grid voltage changes are difficult to achieve. The use of medium power n-channel enhancement mode field effect transistors as grid drivers overcomes the Miller effect by brute force.

Vacuum tube plate dissipation is a function of operating voltage capacitive load and switching frequency.

$$P = \frac{1}{2}\,CV^2f$$

where: P = plate dissipation of either vacuum tube in watts

C = total load capacitance in farads

V = peak electrode voltage in volts

f = switching frequency in hertz.

At 4.0 MHz switching frequency each vacuum tube will dissipate:

$$P = \frac{1}{2}(71.5\text{X}10^{-12}\text{F})(1000\text{V})^2(4\text{x}10^6\text{Hz}) = 143 \text{ watts} \quad (5)$$

Switch tube V_1 has a string of zener diodes and by-pass capacitors in series with its' cathode lead. The zener diodes develop a relatively constant bias voltage to keep V_1 cut-off when V_2 is conducting. Grid drive for V_1 (Point C in Fig. 2) is of sufficient magnitude to overcome the zener diode bias and drive V_1 into saturation. The 50Ω series resistor in V_1 grid circuit serves to damp oscillations and limit grid dissipation.

The tubes are fitted with isolated water cooling jackets and fans provide air cooling to the tube sockets. Figure 3 shows a photograph of the deflection electrode signal.

Acknowledgements

This work is the further development of a concept first implemented by Kenneth W. Johnson and Benny E. Clifft (Argonne).

Work supported by the U. S. Department of Energy, Nuclear Physics Division, under Contract W-31-109-ENG-38.

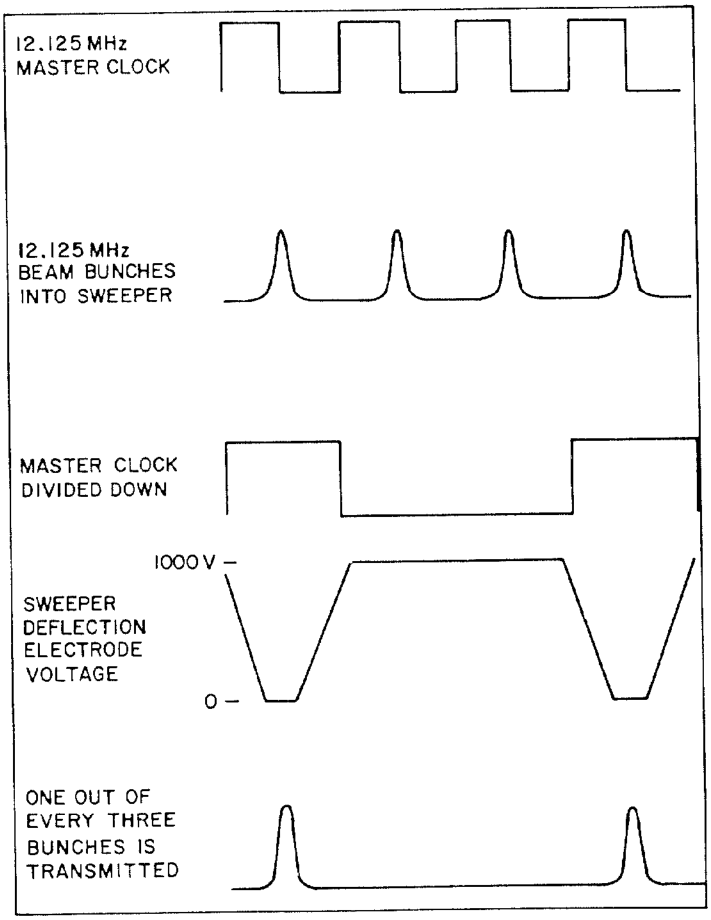

Fig. 1 Sweeper timing relationship.

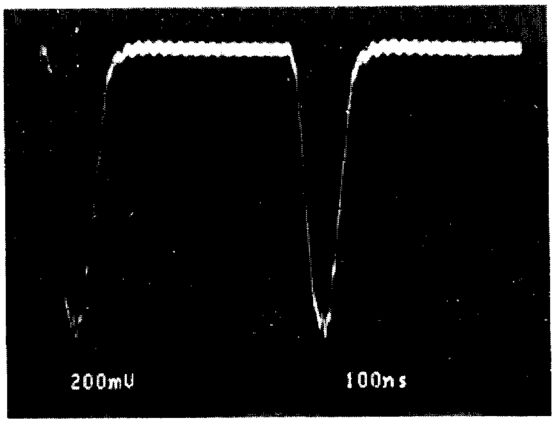

Fig. 3 Sweeper output voltage.

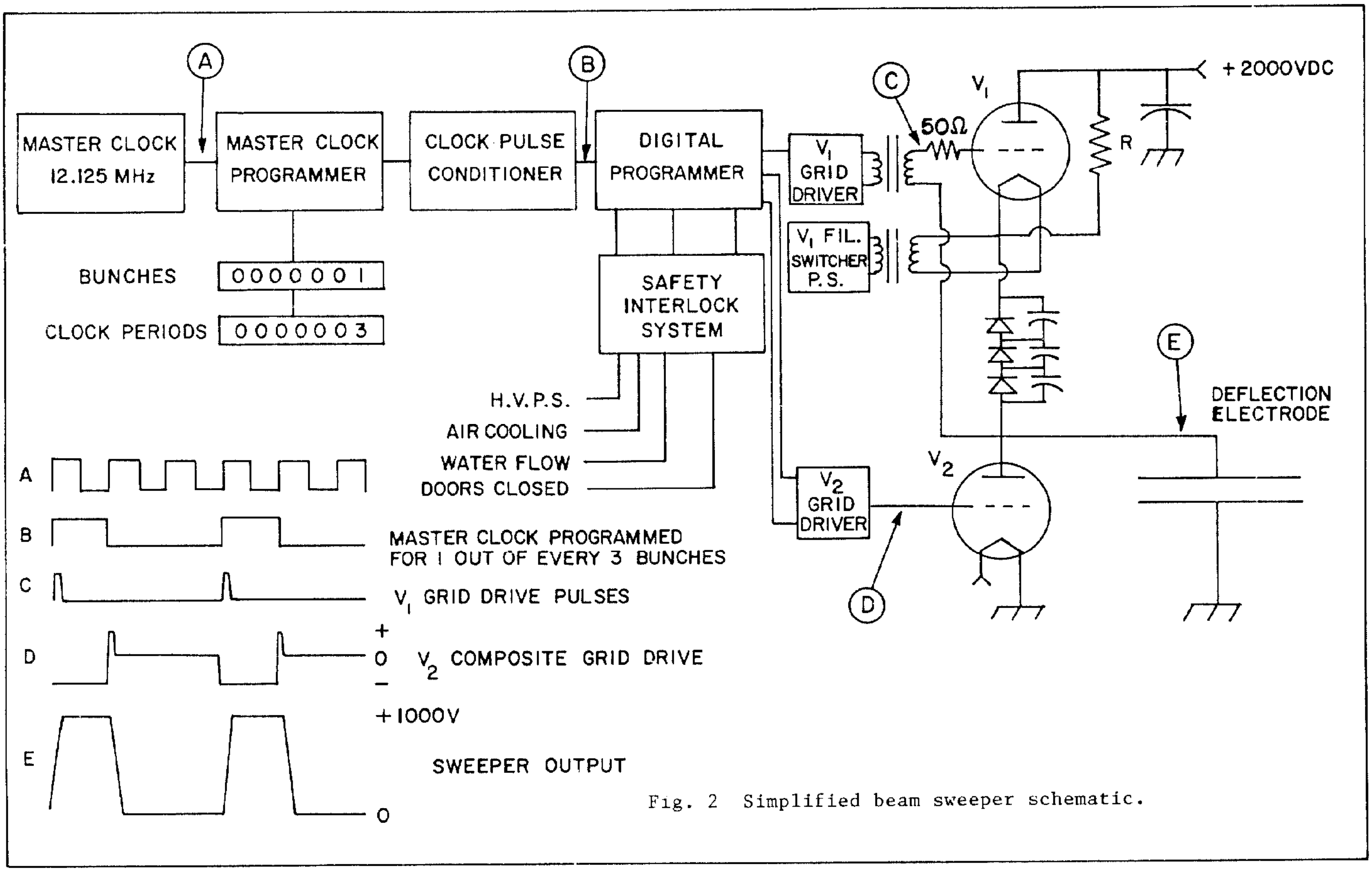

Fig. 2 Simplified beam sweeper schematic.