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AN ANALOG RF GAP VOLTAGE REGULATION SYSTEM FOR THE ADVANCED PHOTON SOURCE STORAGE RING*

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Abstract

An analog rf gap voltage regulation system has been designed and built at Argonne National Laboratory to maintain constant total storage ring rf gap voltage, independent of beam loading and cavity tuning effects. The design uses feedback control of the klystron mod-anode voltage to vary the amount of rf power fed to the storage ring cavities. The system consists of two independent feedback loops, each regulating the combined rf gap voltages of eight storage ring cavities by varying the output power of either one or two rf stations, depending on the mode of operation. It provides full operator control and permissive logic to permit feedback control of the rf system output power only if proper conditions are met. The feedback system uses envelope-detected cavity field probe outputs as the feedback signal. Two different methods of combining the individual field probe signals were used to generate a relative DC level representing one-half of the total storage ring rf voltage, an envelope-detected vector sum of the field probe rf signals, and the DC sum of individual field probe envelope detector outputs. The merits of both methods are discussed. The klystron high-voltage power supply (HVPS) units are fitted with an analog interface for external control of the mod-anode voltage level, using a four-quadrant analog multiplier to modulate the HVPS mod-anode voltage regulator set-point in response to feedback system commands.

1 APS GAP VOLTAGE CONTROL REQUIREMENTS

The APS utilizes a 7-GeV storage ring to generate synchrotron light for material research. The ring is designed to store 300 mA and has been operated routinely at 102 mA maximum current to date. The storage ring uses 16 single-cell cavities, arranged in groups of four at discrete sectors, to generate 9.4 megavolts of total rf gap voltage. Four 1-MW rf stations are used to supply power to the cavities, and a waveguide switching/combining system allows operation of the storage ring with any two or more of the four rf stations simultaneously.

Because the maximum beam loading in the storage ring cavities will represent a coupling coefficient of approximately 4, the amount of rf power required to maintain 9.4 megavolts of total rf gap voltage varies widely depending on the amount of stored current [1].

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The present method used to regulate total storage ring gap voltage is a "control law" software program, utilizing two separate software amplitude control loops. This system has worked well, but it can only sample the cavity field probe powers and make adjustments to the rf system output power at a rate no faster than 1 Hz. This slow data acquisition and transmission rate has caused delays in reducing the output power of the rf stations, resulting in rf system trips. The trips occur when the storage ring beam is suddenly dumped or lost, resulting in an instantaneous increase in the rf power dissipation of the rf cavities by an amount equal to the beam loading effect. This sudden increase in power can degrade cavity vacuum and cause damage to cavity components such as tuners and couplers. The analog automatic gain control (AGC) system was developed to provide fast and accurate control of the rf system power output as a function of stored beam current intensity.

2 ANALOG REGULATION SYSTEM OVERVIEW

The analog gap voltage regulation system is a true DC-coupled feedback system for maintaining constant rf gap voltage amplitude in the APS storage ring cavities (see Fig. 1). The system consists of two identical and independent amplitude-control feedback loops. Each loop regulates the combined gap voltage of eight storage ring cavities (a sector-pair) by making real-time adjustments of the rf power into the cavities in response to cavity beam-loading effects. This maintains agreement between the combined envelope-detected field-probe powers and an operator-selected gap-voltage setpoint.

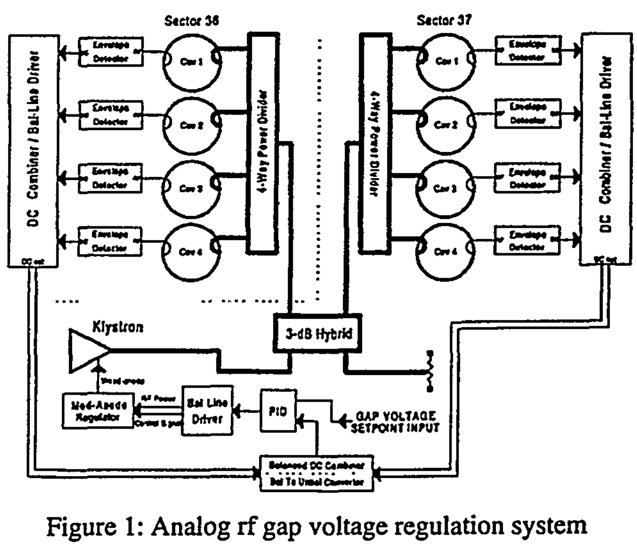

Figure 1: Analog rf gap voltage regulation system

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The ATLAS facility is a heavy ion, superconducting linear accelerator, with the capability of switching between a positive ion injector (PII), and a negative ion injector (Tandem). The Tandem injector is a 9-MV tandem electrostatic accelerator with a negative ion sputter source. The two injectors couple into the 'Booster' linear accelerator. The Booster consists of 46 independently phased, split-ring niobium superconducting resonant structures.

A variety of effects can cause transit time variations during acceleration through the tandem. Some examples of these are stripper foil thickening, source platform voltage variations, tandem voltage profile variations, or poor tandem voltage regulation due to low beam currents on the analyzing slits.. Such variations, if not corrected, would cause the ion bunch to arrive at the linac at the wrong time. Proper acceleration through the linac requires a stable time-of-arrival (TOA) at the entrance to the linac. The transit time through the tandem is typically 10μsec, it would be preferable to match the arrival time with an accuracy of 0.1 nsec, clearly some form of phase stabilization is need.[1]

The detector used for normal intensity beams from the tandem is a room temperature helix resonant structure which measures the TOA of the beam near the entrance of the linac. The beam bunch excites a the helix resonator and the induced RF phase with respect to the master oscillator is a measure of the time of arrival. The lowest beam sensitivity for this helix structure is around 1 enA. With the need to accelerate and stabilize the time of arrival of a low intensity beam, a new method of stabilization was necessary.[1]

APPARATUS

The new low-beam-current detection system is located about 0.25 meters downstream from the Tandem energy analyzing slits. This position, shown in figure 1, is desirable because the charge state ,mass, and energy of the ion of interested have been selected by the 90 degree analyzing magnet. The device is on a precision adjustable bellows feed-through, Model number PMZ-275-2, purchased from Huntington Mechanical[2]. This enables precision insertion, approximately 0.4mm position repeatability, of the scintillator tip into the outside fringes of the beam. The assembly is mounted vertically on the beam line A vertical insertion, rather than a horizontal insertion, is desirable, because in the horizontal position it is possible to experience a tandem voltage fluctuation that may cause the 90 degree analyzing magnet to sweep the full beam current onto the scintillator and thereby damaging the scintillator.

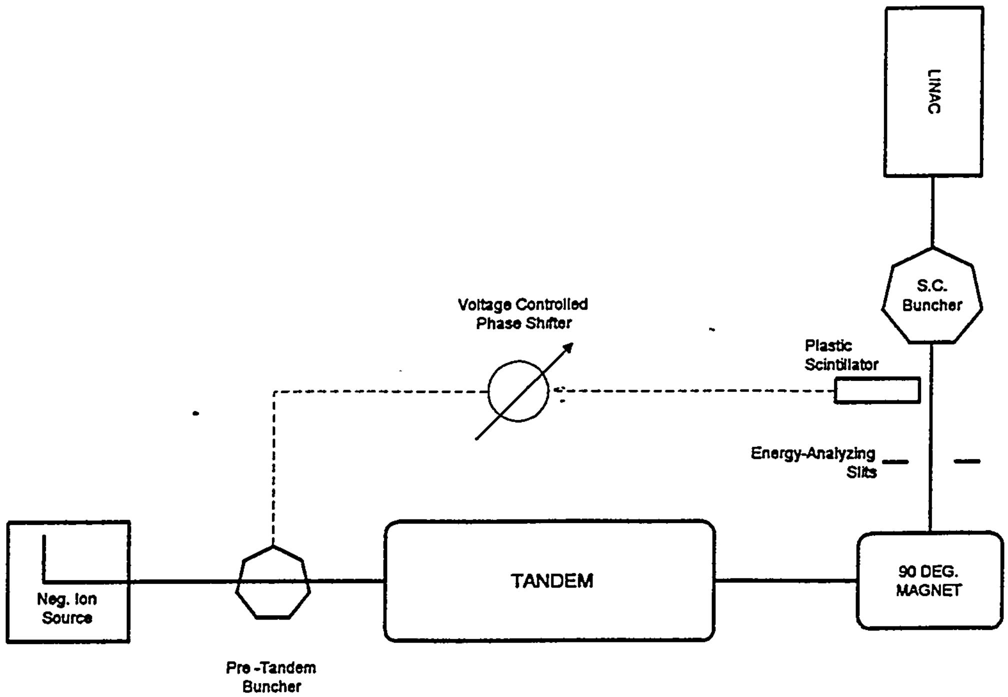

FIGURE 1. Diagram of the tandem accelerating system showing the scintillator slit position.

The scintillator material is supplied by Bicron Corporation[3], number BC408, and is coupled to a photomultiplier tube, R1635, model WB1432 purchased from Hamamatsu Corp[4]. The scintillator tip is the only piece of the assembly that is in the vacuum. An O-ring seal on the shoulder of the scintillator material provides the vacuum / atmosphere interface between the scintillator and the tube. This construction minimized the amount of material in the vacuum space, and allowed the tube and socket to be replaced without the need for venting the vacuum. Figure 2 illustrates the vacuum assembly of the apparatus.

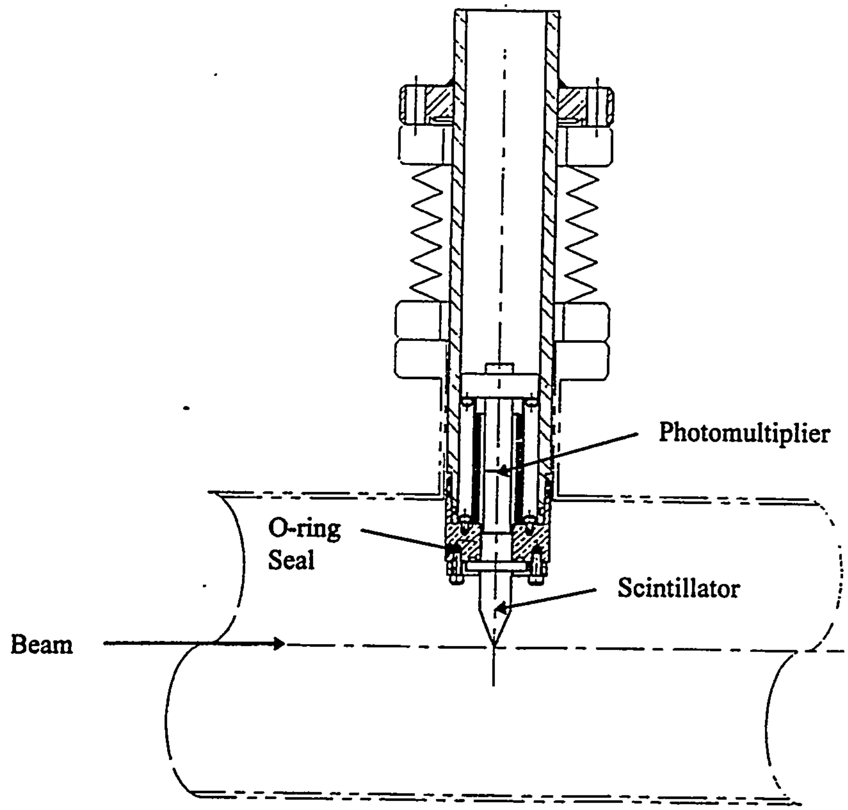

FIGURE 2. Drawing of the scintillator on the bellows feed-through

A phase-lock control circuit was constructed to use the pulses generated by intercepting a small fraction, approximately 1%, of the beam current on the scintillator and convert it into an input control signal for the existing voltage-controlled phase shifter of the pre-tandem buncher. The pulses from the photomultiplier tube of the scintillator are fed into an octal discriminator. The discriminator level is set to reject any equivalent low energy noise out of the scintillator thereby filtering out any signals that are not within 10% of the beam energy. The TAC output is split into a single channel analyzer (SCA) and an Evens Electronics[5] Gated Integrator Module (GIM), model # 4138A. The SCA upper and lower discriminators are set to bracket the desired signal level from the TAC. The GIM only samples the time-to-amplitude converter (TAC) output level at a valid gate signal and it's output holds the TAC signal as a DC voltage. This DC voltage is amplified and offset using an internal DC offset adjustment. This is then fed into a voltage controlled phase shifter that controls the phase of the pre-tandem buncher. The DC offset sets the "correct" value so as to produce no shift at the desired beam TOA. Any error in the beam TOA forces the phase shifter to the correct TOA. Figure 3 is a block diagram of this circuit.

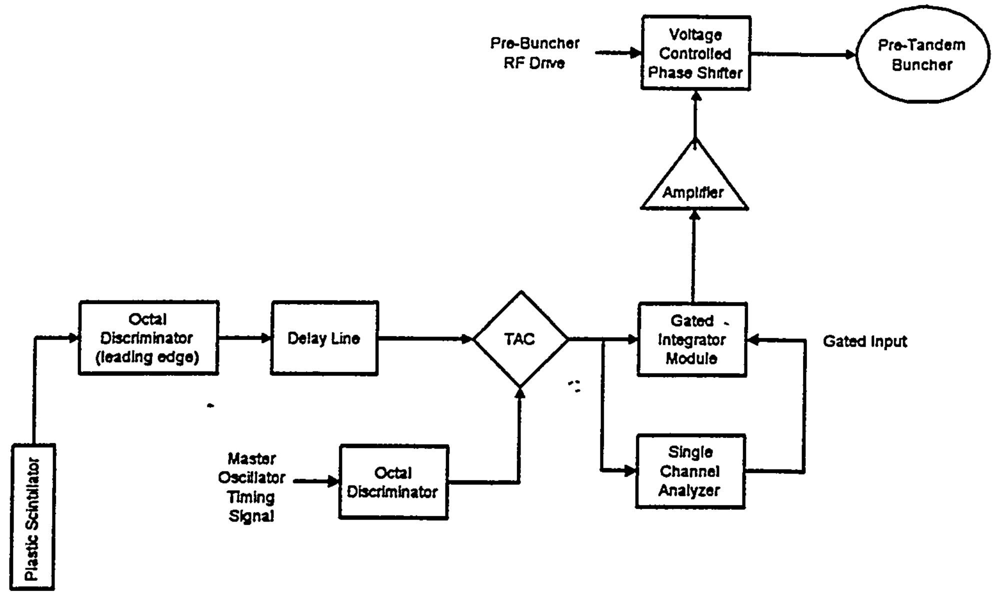

FIGURE 3. Block diagram of the electronics for the phase lock loop of the scintillator detector.

TEST

To test the entire system a guide beam of $^{28}Si^{+5}$ was accelerated through the Tandem. The $^{28}Si^{+5}$ has the same charge to mass ratio of the radioactive beam $^{56}Ni^{+10}$. By using the stable Si beam, the accelerator can be tuned with a measurable amount of beam and then by dramatically attenuating the beam test the new low beam current detector system.

The normal configuration of the spiral detector and the 90 degree magnet energy analyzing slits were used to set up the accelerator. A silicon barrier detector, located at the exit of the booster accelerator, measured the timing centroid of the guide beam. The timing centroid was observed for a period of time to determine that the terminal voltage was stable and not contributing to any shifts in the centroid. Once the timing centroid was determined, and a calibration of the silicon barrier detector's count rate vs beam current was performed, the beam was attenuated to a current of 1.68 X10^4pps. At this low beam current the scintillator was inserted to yield a count rate of 200 Hz, which was approximately 1.2% of the beam current, and the phase lock loop control of the pre-tandem buncher was switched to scintillator control system. This rate was sufficient to allow active feedback for TOA variations slower than approximately 60 Hz.

To introduce a timing shift into the beam, and to test the control capabilities of the new detector system, the platform voltage of the negative ion source was varied. The normal operating voltage of the platform is 150kV. At 150kV the timing centroid on the surface barrier detector was measured. The control loop was switched off and the centriod was measured again, it remained the same. The platform voltage was then dropped to 149kV. The timing centroid shifted 12.61ns. The deck voltage was returned to 150kV, the loop was switched on. To check the effectiveness of the phase lock loop the deck voltage was changed to 148kV, with the control loop on, and the resulting change in the timing centroid was 0.67ns. This 2kV test shift is well in excess of the maximum normally expected shifts of 100 -200 volts. We infer from these measurements that the TOA of the beam is stabilized to approximately 0.1nsec for reasonable, short term, fluctuations in the tandem accelerator.

Table 1 Summary of the Open and Closed Loop Results

	ΔV Platform	Terminal Voltage	ΔT
Open Loop	1kV	8.450MV	12.6ns
Closed Loop	2kV	8.450MV	0.67ns

Stability tests were conducted for two days. The timing centroid was monitored on the silicon barrier detector using 1.68 $X10^4$pps of $^{28}Si^{+5}$ tuned through the accelerator. The tests showed a maximum long term drift in the timing centroid of 0.6ns.

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REFERENCES

1. F. J. Lynch, R. N. Lewis, L. M. Bollinger, and O.P. Despe, Necl.Instr. and Meth. 159, 245 (1979)
2. Huntington Mechanical Laboratories Inc. Mountainview, California
3. Bicron Newbury, Ohio
4. Hamamatsu Corporation Bridgewater, New Jersey
5. Evans Electronics Berkely, California