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BEAM INSTRUMENTATION FOR THE BNL HEAVY ION TRANSFER LINE*

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Abstract

The Heavy Ion Transfer Line (HITL)[1] was constructed to transport beams from the BNL Tandem Van de Graaff (TVDG) to be injected into the AGS. Because the beam line is approximately 2000 feet long and the particle rigidity is so low, 20 beam monitor boxes were placed along the line. The intensity ranges from 1 to 100 nanoAmps for the dc trace beam used for line set-up, to over 100 μA for the pulsed beam to be injected into the AGS. Profiles are measured using multiwire arrays (HARPS) while Faraday cups and beam transformers monitor the intensity. The electronics stations are operated through 3 Instrumentation Controllers networked to Apollo workstations in the TVDG and AGS control rooms. Details of the detectors and electronics designs and performance will be given.

Introduction

The AGS requires a 20-250 μsec beam pulse each 1-3 sec. At 100 μA current this provides up to 2×10^{10} O^{+8} ions. For setup a "trace" dc beam of 1-20 nA sent down HITL is monitored at a 10 Hz rate. In the AGS mode, the short beam pulses used for fractional turn injection require risetimes <5 μsec for intensity monitoring and integration windows as short as 20 μsec for profile measurements.

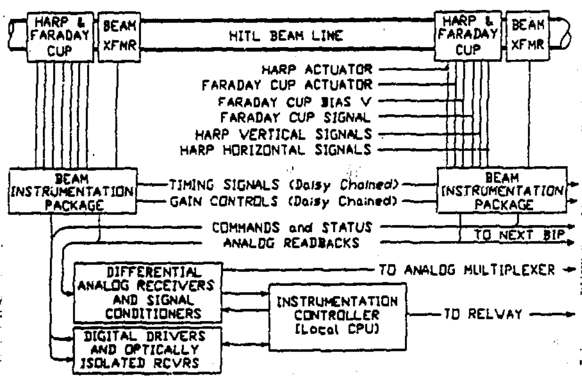

Figure 1. Beam instrumentation signal flow in HITL.

Beam Instrumentation Packages (BIPs), located 10 feet from the diagnostic chamber, house the analog and digital interface electronics. The signal flow is shown in Figure 1. Timing signals and gain control bits from the microprocessor based Instrument Controller (IC) are daisy-chained from BIP to BIP. Specific command and status bits go directly between BIP and IC. Analog profile and intensity signals from each BIP go to the ADC in the IC and an analog signal multiplexer system. Each of the 3 ICs services up to 8 BIPs. Beam profiles, updated at 10 Hz, may be viewed on scopes in the TVDG or AGS control rooms. Digitized profile and intensity data can be displayed graphically or used in computations at any Apollo workstation.

The HITL tunnel is a good environment for low level measurements due to careful planning of ground breaks, low noise lighting, use of non-SCR power supplies and location of electronics near detectors. Optical isolation of digital signals and twisted pair transmission of analog signals to differential receivers reduce ground loop problems. Breaking grounds between the detectors and BIPs did not affect the signals, which come from true current sources. Deployment of the instrumentation is shown in Figure 2.

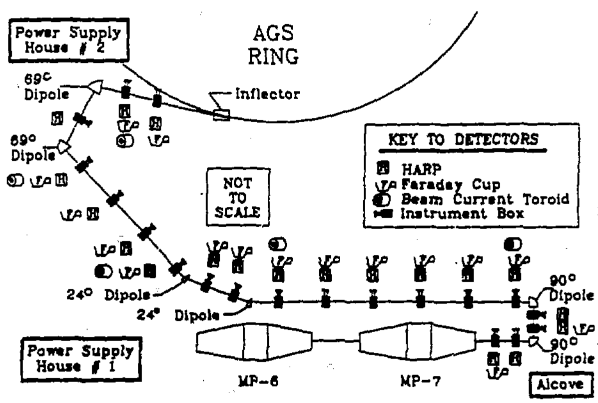

Figure 2. Locations of beam instrumentation in HITL.

The BIPs (Fig. 3) were designed with special consideration for modularity, ease of handling, repair and manufacture. A standard 48"-high cabinet contains the "Top", HARP and optional HARP Expansion NIM crates, Power Supply chassis and 500 VA isolation transformer. The Top crate houses the Digital Interface modules to/from the IC, the Faraday Cup Amplifier, Beam Current Transformer Amplifier and Device Actuator modules. All electrical signals go through plugs on the cabinet side panel. Connections to each NIM crate are through a "doghouse" mounted over the rear NIM connectors. Mass terminated connectors were used for HARP signals. The Power Supply chassis provides +5 Vdc, ±15 V, 24 Vdc for the actuators, and 600 V bias, for the Faraday cups. An additional floating 5 V suppply in the top crate provides isolated power for the digital drivers.

Hardware

Profile Measurements

Beam profiles are measured at 20 places (Fig. 2) with multiwire arrays (HARP). Currents from the wires due to incident ions and secondary emission are integrated and sequentially multiplexed out. The commercially[2] made HARPs have orthogonal grids of spring loaded .004" tungsten-rhenium wires at .5, .75 or 1.20 mm pitch. All materials are metal or ceramic, including the connectors, which allows the HARP to remain in place during the bakeout required to reach 10^{-9} Torr vacuum. Each HARP is attached to an air actuator mounted on a 100 mm Conflat flange which it shares with a Faraday cup drive. Actuation time is <250 msec. Limit switches sense arrival at mechanical stops. Precision manufacturing allows swapping of units without resurvey.

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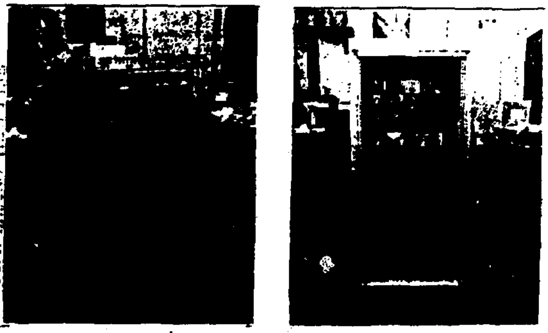

Figure 3. BIP containing 64 channel HARP electronics.

The electronics (Fig. 4) sequentially scans the charge from the wires integrated over a settable window. Each crate can scan 32 wires. Three crates can be parallelled to display up to 96 channels. In 15 places, only 16 wires from each plane are read. The HARP Configuration Box allows selection of those to be read and grounds unused wires in any of 5 patterns: center 16, center 8 and 8 outer, alternate, or all 32 from the H or V plane. A HARP crate contains Integrator Timing, Multiplexer Control, 32 Channel Multiplexer, and eight 4-Channel Integrator modules. The HARP Expansion crates are wired the same as the HARP crate but contain only the 32 Channel Multiplexer and Integrator modules with timing and control signals daisy chained from the HARP crate.

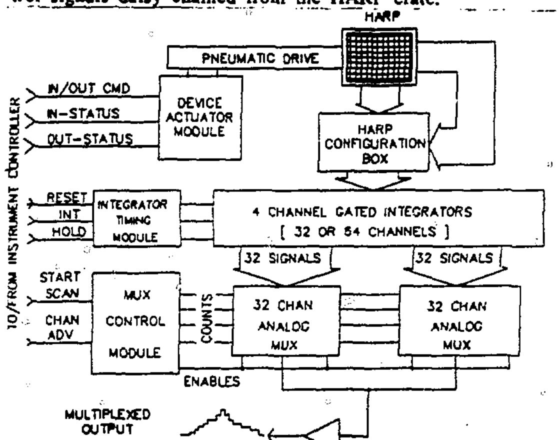

Figure 4. Block diagram of the HARP electronics.

Signal currents can vary from less than 100 pA to 10's of µA. This range is accommodated by using a gated integrator and adjusting the window from 20 µsec to 88 msec. A relay switches integrator capacitors for another factor of 5. A single width integrator module contains 4 circuits which feature charge injection compensation and offset adjustment. The printed circuit board was designed with special care to guard the entire input line from leakage. Ultrasonic cleaning, followed by baking and spray coating, reduced the effect of humidity, resulting in leakage of <10 pA. A total of 824 integrator channels were installed.

The channel select logic is provided by a counter in the Multiplexer Control module. In COMPUTER mode, the CHANnel ADVance pulses are supplied by the IC. In LOCAL mode these are generated by an internal crystal clock triggered externally or from the Integrator Timing module. The scan can be jumper selected from 32 to 96 channels in 4 steps.

The Integrator Timing module provides the RESET, INTegrate and HOLD pulses for the integrator window. In LOCAL mode front panel controls set the repetition rate from 0.1 to 2 sec and integration time from 20 µsec to 100 msec. In COMPUTER mode the module echos pulses sent by the IC, and disables the front panel controls. In either mode, HOLD triggers the Multiplexer Control module to start the scan of the 32 Channel Multiplexer.

These modules permit 3 timing modes: 1- Full computer control, 2- External beam trigger with local or external integrate time and local scan, and 3- Fully local, asynchronous scan. In the computer mode, scanning of the HARP for scope display occurs even if the IC is not digitizing the data.

Faraday Cups

Beam current is monitored at 17 places (Fig. 2) using commercial[3] Faraday cups. Though destructive, they allow pulsed and dc beams to be measured over a wide dynamic range. A bias electrode (-600 V) surpresses secondary emission. The stainless steel frame and alumina insulators allow the assembly to remain in place during bakeout. The conically shaped, uncooled (600 W maximum) tantalum cup has a 1.2 inch aperture. The same type actuator is used as for the HARP, with which it shares a common flange.

The amplifier consists of 2 OP37EZ opamps and a LH0002 driver. Two bits provide 2 mode and 2 gain states. In the dc mode (10/100 nA/V) the bandwidth is reduced to 1 kHz to limit noise. The pulsed mode (10/100 µA/V) bandwidth is 500 kHz. Offset in the high gain/dc mode is the only adjustment.

Device Actuator

The Device Actuator module translates commands from TTL levels to 24 Vdc for control of the pneumatic drives and provide TTL status bits for IN and OUT. Opto-22 units in this dual channel module isolate the control and limit signals between the BIP and beam pipe. Local control and readout is provided.

Beam Current Transformer

Pulsed beam current is measured non-destructively by a beam transformer. The beam passes through the aperture of a high permeability toroidal core, acting as a single turn primary winding with the signal taken from a secondary winding. The HITL beam current transformer is modelled after the design of Browman[4] at LANL, later used on the BNL polarized H^- beam.[5] Multilayer magnetic shielding and air-filled acoustic isolation mounts reduced the noise. In the HITL design the 83 pound supermalloy core was replaced by a 1.4 pound core with twice the winding turns. While this reduced the inductance, the droop was 0.1% over the 200 µsec beam pulse. In the original unit, winding resonances limited the risetime to 20 µsec. Damping resistors, periodically placed around a uniformly spaced winding,[6] resulted in <5 µsec risetime through the amplifier. One of the 5 installed transformers was upgraded in this way.

The electronics consists of a differential amplifier first stage, followed by 3 OP37EZ stages and and LH0002 buffer stage. The gain can be switched from 10 to 100 µA/V by FETs. A baseline restorer circuit was installed in the Alcove crate to reduce the effect of 60 Hz pickup. The baseline signal sampled just prior to beam time is subtracted during the pulse, reducing 60 Hz noise to about 10 mV.

The Alcove Crate

Analog signals from the BIPs in the tunnel are carried on twisted pairs to 8 Channel Analog Receiver modules in the Alcove Crates in the TVDG Alcove and Power Supply Houses I and II. The circuit has a terminated differential input for ground isolation, 350 kHz bandwidth, 60 db CMRR, and a gain of 0.95 to 2.5 for cable loss compensation. The output can drive a 51 Ohm termination. The Baseline Restorer module is also located in this crate. Four Channel Integrators for the Faraday Cup and Beam Transformer signals give the charge for the full width beam pulse. Integration of the beam transformer signal over a pulse window is provided by another integrator module.

Computer Control

Measurements are made using 3 microprocessor based Instrumentation Controllers (ICs), about 1000 feet apart at the lowest level of the HITL distributed control system.[7] Apollo workstations in consoles at the AGS and Tandem control rooms, are connected to Stations via RELWAY, a broadband network developed at BNL. The Station is connected to device controllers, including the ICs, by the IEEE-488 bus. The ICs get simple commands and setpoints from their Stations and send back status and data reports.

PROM based IC code written in PLM runs under the Intel RMX-88 operating system. The hardware is housed in a Multibus card file in a shielded crate. It consists of an SBC 88/25 processor, with 32K RAM, I/O expansion, Timing, 32 channel 12 bit ADC and logic boards. This allows control of 8 HARPs, 6 Faraday cups and 2 beam transformers, with room for expansion. Digital I/O to the BIPS is optically isolated at both ends. Each Faraday cup, transformer and HARP uses an ADC channel, with the HARP wires time multiplexed at 6.67 kHz.

HARPs and Faraday cups can be inserted by the IC in several modes: simple INSERT/RETRACT, PLUNGE/AGS (for pulsed beam only), and PLUNGE/DC (for dc beam only). The IC sets the gain and integrate delay and width for HARPs and provides the RESET and CHANnel ADVance for the multiplexer. The gain bits for Faraday cup amplifier and beam transformer amplifiers can be set through the IC. Digitization of the dc current or integrated charge for the pulsed beam can be obtained.

Analog Multiplexer

The computer controlled Analog Multiplexer (AMUX) switches signals to scopes in the consoles. Four IEEE – 488 controlled commercial units of 128 reed relay pairs each, are configured as a 64 x 8 multiplexer, with 4 outputs going to the AGS and 4 to the TVDG. All AMUX inputs are buffered by 8 Channel Differential Analog Receiver Modules. The 8 outputs of the AMUX go to high input impedance drivers, allowing multiple viewing of the same signal. These twisted pair output lines terminate in the same type circuits in the control consoles for isolation and noise rejection.

Operational Results

The HARPs are the main tool for tuning the HITL line. DC 0^{+8} beams of 10 nA produced 1 V peaks with 10 mV channel offsets. In pulsed mode a 10 μA beam across 3 wires gave a peak signal of 200 mV for a 20 μsec integration time. The matching of wire spacings to beam sizes was appropriate for normal running. Channel offsets, initially set to ±10 mV, have been stable for 1 year and could be further nulled if needed. The ~7 MeV/AMU 0^{+8} beam is attenuated 15 to 25% by the HARP depending upon wire spacing and beam radius. Several times wires have been burned out by the beam. A dc beam of 2-300 nA and 1 mm radius destroyed wires on a HARP left in the beam. A pulsed beam of about 1 mm radius and 200 μA burned wires after some finite number of 250 μsec pulses at 2.5 sec interval. HARPs are now used in plunging mode only for pulsed beam and with 10-30 nA dc beams. A photodetector to sense glowing wires and retract the HARP is under development.

The Faraday cup signals exhibit 5 mV noise (high gain) at the BIP and 20 mV after the AMUX. This is easily filtered in the DC mode. In pulsed mode the risetime is <1 μsec at the BIP output. Long term offset stability has been very good.

Initially the beam current transformers all were built to have 20 usec risetimes. the noise observed was approximately 50 nA. For injection studies, AGS ring monitors required beams of <25 μsec (partial turn). The low noise allowed the bandwidth of one transformer and amplifier to be extended for risetime of <5 μsec but the noise increased to about 150 nA.

Mechanically the commercial hardware has been very good. Vacuum in the diagnostic chambers is typically in the 10^{-9} Torr range but a few units are sometimes higher. Aside from the wire burnout no failures have occurred.

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