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A MULTI-WIRE CHAMBER SYSTEM FOR HEAVY ION BEAM MONITORING AT THE BEVALAC*

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Abstract

Horizontal and vertical integrated beam-current profiles are generated by a system of multi-wire chambers (32 wires/profile) operating in either the ionization or proportional mode. Sixteen distinct displays (1024 words) are digitally stored and any four may be simultaneously displayed. A new display can be generated at 64 ms intervals. A central control unit selects the mode of operation, the amount of delay after an appropriate trigger, the chamber integration time, and the particular chambers to be displayed. Operating in the proportional mode relativistic heavy-ion beam intensities as low as 10^4 charges cm^{-2} sec^{-1} can be detected.

Introduction

Relativistic heavy ion beams have been produced at the Berkeley Bevatron since 1971. More recently the Bevalac has begun operation as a national heavy ion facility for nuclear science and biomedical experimentation. The initial phases of the Bevalac operation are described in detail in several other papers presented at this conference.[1,2] Ions as heavy as Argon have been accelerated to 2 GeV/nucleon and a Krypton beam is expected in early spring.

Heavy ion beams at relativistic energies in the laboratory are unprecedented and pose a unique monitoring problem. Fragmentation of the primary ions into nuclei of lower atomic number occurs with a relatively high probability ($\sigma_{frag} \sim 1$ barn) when passed through matter. The loss of one nucleon results in the eventual removal of the parent ion from the beam channel due to its change in magnetic rigidity. Fragments which preserve the charge-to-mass ratio and longitudinal velocity of the parent ion are sources of background which contaminate a subsequent experiment. In addition, the high charged state, Z, of fully stripped ions and the Z^2 dependence of their energy loss in matter, introduce restrictions on the amount of materialallowed in the beam line if the momentum bandwidth is to be minimized.

Initial heavy ion beam intensities were low and SEMs , beam transformers, and plastic and zinc sulfide scintillators normally used for proton intensities were inadequate for monitoring and tuning the labyrinth of external beams in the experimental area. Nuclear emulsions, Polaroids and X-ray film provided useful information, but were disruptive and time consuming. An image-intensified scintillator with video output was developed and proved useful for tuning in limited applications.[3] Tuning periods were lengthy and reproducibility was difficult to achieve. Real-time monitoring was non-existent and slowly drifting parameters in the transport lines escaped proper detection. Monitoring was not available for tuning the complicated resonant extraction system of plunged septum dipoles and quadrupoles.

A suitable monitor would possess low mass, a wide dynamic range to span the beam intensities from protons to Krypton, and be capable of providing detailed intensity and spatial information. Again borrowing from high energy proton physics, a proto-type current integrating multi-wire chamber was built and tested. The system described here is the result of these early tests. In addition, a versatile readout, storage, and display digital electronics design capable of handling up to sixteen individual wire-chambers in several complimentary modes of operation was developed.

Originally designed to facilitate the tuning and monitoring of primary external beams, the chambers have found additional uses in secondary beams.[4] The chambers are of rugged physical construction and thus far have been maintenance free. The readout system is sensitive and possesses good noise rejection. The chambers are fixed in air gaps in the beam or remotely positioned in the beam vacuum pipe. More recently a chamber has been located on the plunged septum magnet assembly in the main accelerator ring. With it the beam radial growth necessary for efficient resonant extraction can now be determined at low intensity.

Multi-Wire Chamber Mechanical Description

An exploded view of the multi-wire chamber assembly is depicted in Fig. 1. The two orthogonal signal wire planes are rotated 45° about the chamber axis to symmetrize construction and enable all utilies to be accessed from one edge, thus minimizing protuberances on the other sides. This seemingly minor design point has proved very useful around the extremely crowded and inaccessible architecture of the Bevatron structure.

The signal planes are composed of two 32-wire grids wound with two or six mm centers. The smaller spacing allows monitoring waists in the beam while the latter is used at quadrupole apertures where beam cross sections are large. The wires are 0.051 mm Be-Cu epoxied and soldered to PC boards mounted on Nema G-10 frames. The wires are wound at 80 gm of tension and terminate in two 32-pin Bendix connectors. Grounded field-shaping wires are added to both ends of the signal wire array to insure uniformity of response at the extreme ends.

The two signal planes are interleaved between three HV planes and epoxied in place. Be-Cu wires 0.051 mm in diameter are wound with 1 mm centers, epoxied, and soldered to a copper bus to form the HV plane. The three HV planes have a common termination at the Reynolds 10 kVdc connector. A protective resistor limits the current in the event of sparks between wire planes. The HV planes are mounted to

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4 mm thick Nema G-10 boards which form the gap spacing. The chamber gas mixture is routed through the two outermost HV plane frames.

Chambers operated in air gaps in the beam lines are sealed with 0.13 mm Kapton windows. Fig. 2 depicts the assembly for remotely positioning chambers within the vacuum. The gas seals on these chambers consist of 0.25 mm aluminum windows with O-ring seals. In either case the amount of material presented to the beam does not exceed 150 mg/cm^2. The linear dimension along the beam line required by the chamber and vacuum assembly is less than 9 cm.

The chamber located in the main ring vacuum (3×10^{-7} Torr) of the accelerator is pictured in Fig. 3. The retractable chamber assembly is mounted on the plunged septum magnet and must withstand acceleration forces in excess of three gs. A harness assembly transmits the chamber analog signals and input HV to the chamber through a bulk-head in the main ring vacuum tank. The chamber is sealed in a 3.2 mm thick aluminum box. The assembly was evacuated, filled with Charpak magic mixture (72% Argon, 4% methylal, 23.5% isobutane, and 0.48% Freon 13-B1) and sealed. Two more chambers are planned for the second plunged extraction magnet and a third fixed extraction magnet. These will provide beam profiles much needed for tuning the extraction system.

Readout, Storage and Display Electronics

Fig. 4 is a block diagram of the electronics system designed for processing the intensity profiles generated by the ionization of the beam in the gaseous medium of the chamber. A single-point ground has been carefully maintained throughout to avoid introducing ground loops.

Associated with each chamber location is a 64-Channel Multiplexer Unit. It derives power and timing pulses from the centrally located 16-channel Multiplexer and ADC Unit which, in turn, derives its instructions from the Central Control Unit located at the operator console in the main control room. High voltage is provided by a 5 kV power supply through a 16-channel voltage divider. A switchable high voltage microammeter monitors the dark current ($\leq$ 100 nanoamps) in each chamber.

The operator selects the mode of operation, the delay time from an appropriate trigger, the integrating time during which the chamber will collect data, the chamber(s) to be displayed, and the digital gain required for display. An X-Y CRT completes the display electronics.

64-Channel Multiplexer Unit

The functional diagram of the 64-channel multiplexer is shown in Fig. 5. The chamber is connected to the 64-Channel Multiplexer Unit via 32 individually shielded pairs, six meters long and grouped into two cables to reduce cross-talk. Each twisted pair, is connected to adjacent chamber wires which carry nearly equal signals thereby further reducing cross-talk.

Each signal wire is connected through a protective resistor R1 to a selected 0.047 μF capacitor which integrates the charged deposited on each wire by the ionization produced in the chamber gas. An address decoder, M4, serially connects the MOSFET switches in module M7 to the amplifier M6, a unit gain, high impedance operational amplifier. On alternate scans the capacitor outputs are shorted to ground through the Q1 FET switch. In this manner n beam profile displays are generated in rapid succes (64 ms). The amplified analog signals are transmit to the 16-Channel Multiplexer and ADC Unit.

16-Channel Multiplexer and ADC Unit

The 16-channel Multiplexer and ADC unit, Fig. 6 distributes the clock pulses to all sixteen 64-chan multiplexers. Sequential scanning (M1) begins with first wire from all sixteen chambers, then the seco wire, until all 1024 wires have been connected to t ADC. A 12-bit digital word is converted (M2) and transmitted serially in pulse duration modulation (M every 32 μs to the Central Control Unit in the Bevat Main Control Room.

Central Control Unit

The functional diagram of the Central Control Unit is shown in Fig. 7. The heart of the unit is a 1024 word, 12-bit, circulating memory, M7. The contents of the memory are continuously displayed on a CRT. Part or all of the memory is updated with new information on successive triggers. A flicker-free display is obtained by doubling the sampling rate in between data taking.

Data taking is initiated by a suitable trigger pulse, e.g. "Flat-top ON," delayed by M2. Three modes of data taking are available:

1. Sixteen Times, One Chamber, (16 x 1 MWPC): I this mode of operation only one chamber, selected by S4, is read, discharged, and re-read sixteen times i one second, the nominal spill time of the Bevatron. Each alternate read and reset cycle requires 64 ms. The data collected during the sixteen read cycles are stored in the corresponding memory channels of M7.

2. One Time, One Chamber, (1 x 1 MWPC): In this mode of operation only one chamber, selected again by S4, is read once and the data is stored in the memory channel selected by S3. The integration time during which beam ionization is being collected without scanning is variable with M3 from 32 ms to 3.2 seconds. All other memory channels are unchanged. All sixteen memory channels may be filled with successive beam pulses to be studied at leisure at the end of the sequence. Beam intensities as low as 10^4 charges cm^{-2} sec^{-1} have been detected.

3. One Time, Sixteen Chambers, (1 x 16 MWPC): All sixteen chambers are scanned once for a variable integrating time determined by M3. The data are stored in the recirculating memory channels sequentially.

CRT Display

The data contained in the memory is continuously read out, again beginning with the first wires from all sixteen chambers. Any four memory channels can be simultaneously displayed on the CRT as determined by S5 to S8. Position and gain switches are associated with each display selector. The position switch allows display overlays for purposes of comparsion. The vertical gain is variable in eight steps of factors of two.

Eight of the twelve output bits are converted to analog form in M9 and drive the Y-axis of the CRT display. The two most significant bits determine the trace location on the screen for overlays. The CRT

X-axis is driven by M11. M10 unbanks the CRT when the selected channels are scanned. The Z-axis input is controlled by potentiometer P1 which intensifies every eighth wire brightly and every fourth wire less intensely. The X, Y and Z CRT input signals are buffered and distributed to remote users throughout the Bevalac facility.

A provision for computer link-up exists in the Control Unit although it has not been utilized thus far.

Operation

The system described here is routinely used for monitoring both high intensity protons up to 10^{12} particles cm^{-2} sec^{-1} and heavy ions as low as 10^{4} charges cm^{-2} sec^{-1}. The wide dynamic range is derived from the sensitivity of the electronics, its good noise rejection, and the operation of the chambers either in the primary ionization mode or higher proportional gain region. No attempt has been made to achieve the gains required for detecting individual ionizing events and only integrated beam current profiles are produced. Consequently the chambers are less critical in assembly, utilize larger and more manageable wire diameters, and are less expensive than their particle-detector counterparts, at the expense of more detailed information. The beam intensity profiles generated by the chambers are projections onto a line and an ambiguity exists for beam ellipses which are not upright. A third signal plane rotated with respect to the original two would suffice to resolve the ambiguity.

The system has exceeded its original design criteria and has been instrumental in revealing abnormal time structures in the beam, magnet ripples, improper extraction parameters and other previously unnoticed irregularities in beam structure. It has also provided the real-time spatial monitoring necessary for the exacting requirements of biomedical pre-therapeutic investigations now in progress at the Bevalac.

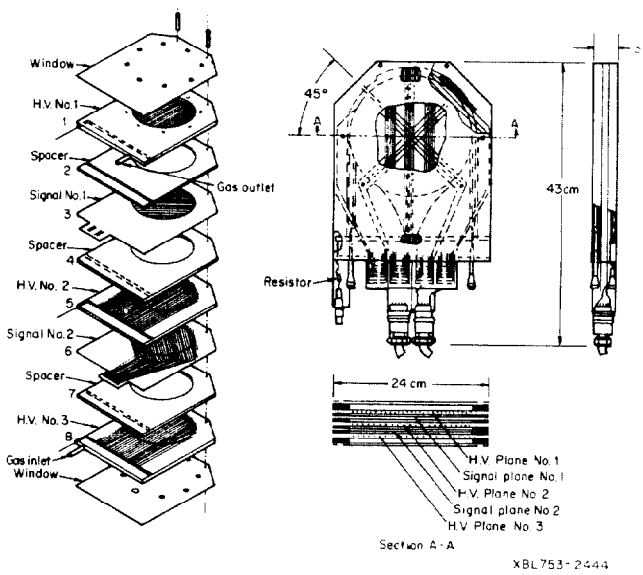

Fig. 1

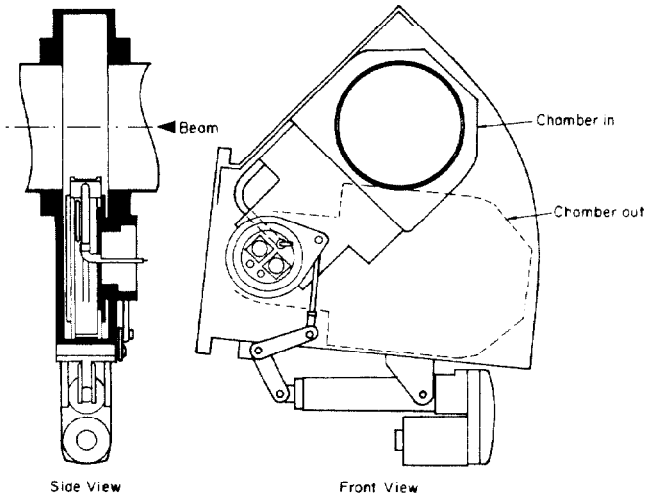

Fig. 2

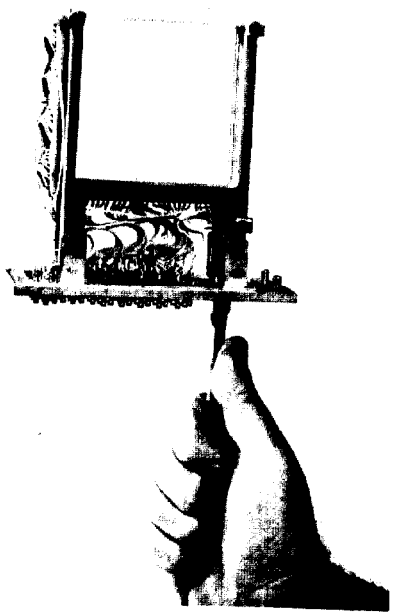

Fig. 3

Acknowledgements

The system described above is the result of the combined efforts of many more people than authorship allows. The named authors would like to thank H. Grunder for his confidence and encouragement, D. Yee and P. Bean for their mechanical designs, O. Draeger for fabricating the chambers, J. Greer and R. Kilgore for testing and debugging the electronics, R. Aita and H. Ellison for installing and maintaining the chambers and the operating crew of the Bevatron for so many helpful and encouraging remarks.

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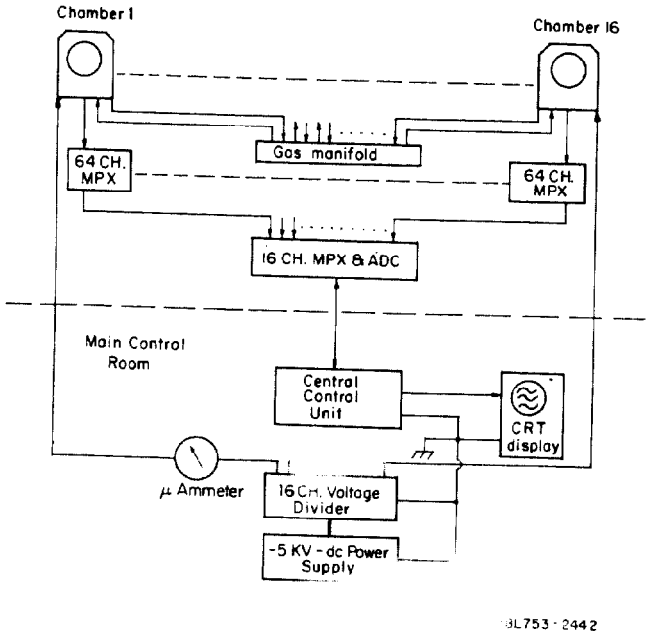

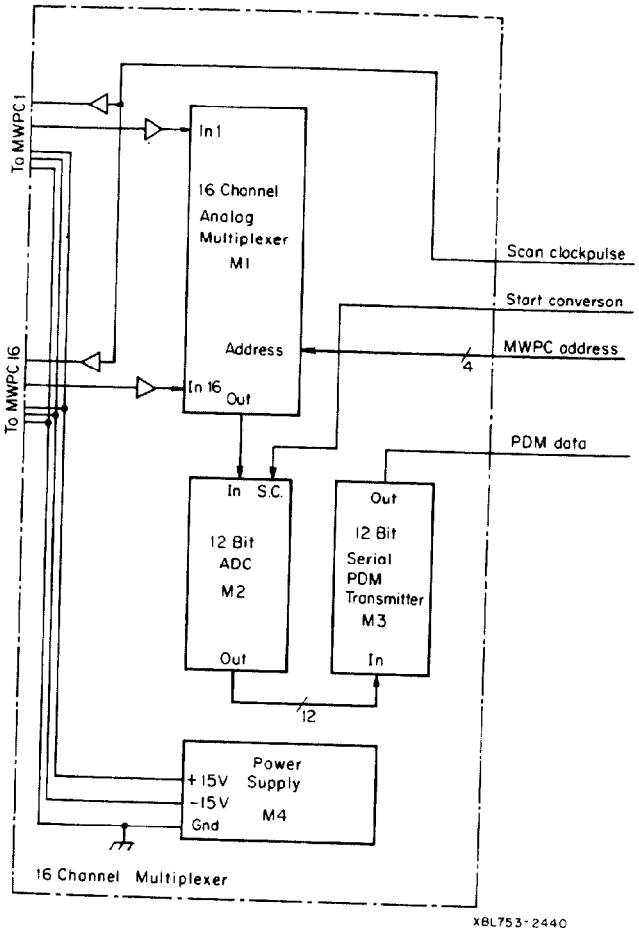

Fig. 6

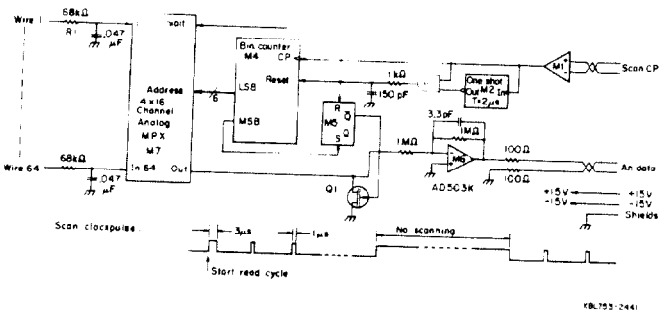

Fig. 5

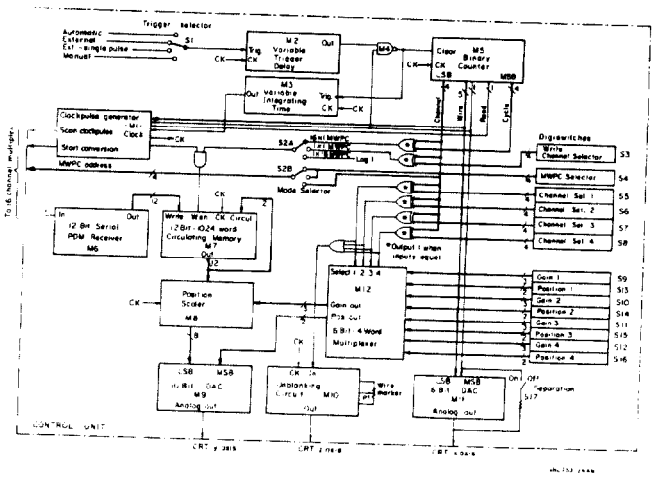

Fig. 7