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Fast Ion Chambers for SLC

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ABSTRACT*

Beam diagnostic ion chambers are used throughout the SLC to perform a variety of tasks including locating beam losses along the beam direction, determining localized losses from individual bunches in a multibunch beam, and detecting scattered particles from beam profile wire scanners where backgrounds are too high to use photomultiplier tubes. Construction and instrumentation of very fast ion chambers with pulse duration of less than 60ns are detailed. Long ion chambers referred to as PLIC (Panofsky's Long Ion Chamber) are the primary diagnostic used to locate losses in all the SLC transport lines. Accurately locating beam loss with the use of fiducial cables and coaxial switches will be discussed.

INTRODUCTION

Normal operation of the SLC requires two bunches of electrons and a single bunch of positrons to be present in the accelerator during each machine pulse. These bunches are approximately 1mm in length and about 60ns apart. In the past, beam losses detected by conventional ion chambers could not be attributed to a particular bunch. The pulse length of these ion chambers ranges from hundreds of nanoseconds to many milliseconds and hence their signals are the sum of the losses from all three bunches. In order to resolve losses from each bunch, fast ion chambers with a minimum pulse length of 35ns were constructed. Fast ion chambers have been installed at collimators or other aperture restrictions in the linac. Their signals are monitored on a real time basis and over long term running.

Wire scanner measurements of beam size are crucial to the successful operation of the SLC.[1] Fast ion chambers are used as wire scanner scattered particle detectors where backgrounds are too high for photomultiplier tubes. They are also used at all other wire scanner installations to provide a cross check on the photomultiplier tubes.

DESIGN

A cylindrical ion chamber design was optimized to: 1) produce pulses of less than 60ns, 2) provide reasonable sensitivity, 3) absorb high radiation without damage, and 4) allow ease of construction.

The body of the ion chamber is a brass tube 30cm in length with an inside diameter of 3.25 mm. For wire scanner applications where the pulse length must be as short as possible, the tube can be sleeved with another brass tube with an inside diameter of 2.35mm. Notching the tubes at either end allows the gas to flow freely when purging impurities. The end of an ion chamber tube is shown in fig. 1. The ends of the brass tube are fitted with insulating standoffs made from Vectra, a plastic which is radiation resistant to 5 x 10^8 rads.

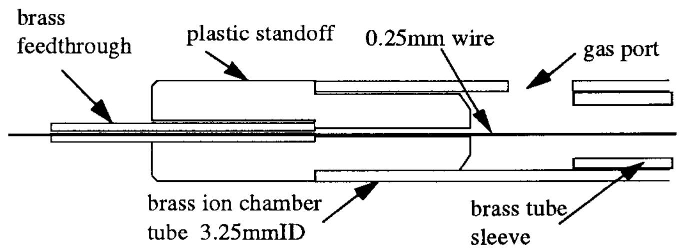

Fig. 1: Crossection of a fast ion chamber tube end

Gold-plated beryllium copper wire with a diameter of 0.250mm is used for the center conductor. The wire is soldered into a feedthrough made from small diameter brass tubing which fits into the outer hole in the standoff. It is then passed through the brass tube, the other standoff and another feedthrough. The standoffs are fitted into either end of the tube. The feedthroughs are seated in the standoffs, then the wire is tensioned and soldered to the second feedthrough. A short length of wire is left on one end to allow for connections. A number of these tubes are bundled together and connected electrically in parallel. The bundle is inserted into two polyethylene rings that act as supports and gas baffles. This assembly is placed inside a 2 inch diameter stainless steel can.

A positive voltage between 50 and 200 volts is applied to the center conductor through a current limiting resistor. The signal is obtained from the center conductor after being decoupled from the high voltage by a capacitor. Ten volt zener diodes are added to the low voltage side of the capacitor in case it breaks down. Originally the ends of the feedthroughs were left exposed at high voltage, and electrons collected over large distances produced tails on the pulse. These tails are eliminated by insulating the ends of the feedthroughs and then covering them with copper foil at ground potential.

The signals of the individual tubes are combined in parallel to increase the output of the fast ion chamber. The tubes have an impedance of about 150 ohms, and three tubes together provide the best match into 50 ohm cable. If more tubes are added, the impedance match becomes worse, and the pulse length increases due to signal reflections at the ion chamber cable boundary. Given the 60ns bunch spacing, 15 tubes is about the maximum number that can be combined and still produce the required pulse length. Ten tubes are used for wire scanner installations.

PULSE LENGTH

For a burst of radiation that is short compared to the electron collection time, the pulse length of a fast ion chamber is determined by the drift velocity of the electrons in the gas and by the distance between the electrodes.

Initial tests were performed using a mixture of 95% Ar and 5% CO_2, which has a maximum electron drift velocity of about 4.5cm/µs. The pulse from the ion chamber using this mixture is shown in fig.2A. Although the pulse length is shorter than the SLC bunch spacing, a much cleaner separation is required for wire scanner beam size measurements.

Experimental results using pure CF_4 or CF_4 in mixtures with argon indicate an electron drift velocity of over 12cm/µs.[2] A fast ion chamber using a mixture of 80%Ar and 20% CF_4, produces the shorter pulse with increased amplitude seen in fig. 2B. This mixture was selected for use in fast ion chambers used as wire scanner particle detectors because of the short pulse length, and high amplitude signals it produced.

Another method of decreasing the pulse length is to effectively reduce the drift distance by using a mixture which contains an electronegative gas, such as Freon. Electrons liberated at large distances from the center conductor recombine with the Freon and do not contribute to the pulse length. The same fast ion chamber using a mixture of 95% Ar, 4.7% CO_2 and 0.3% Freon produced the pulse shown in fig. 2C. This mixture significantly reduces the signal amplitude but is ideal for fast ion chambers used at collimators where the radiation flux is very large.

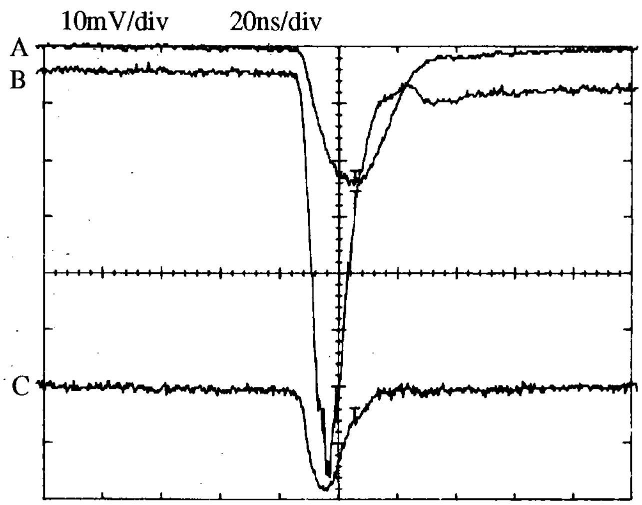

Fig. 2: Fast ion chamber signals with constant beam conditions, using: A) 95% Ar and 5% CO_2, B) 80% Ar, 20% CF_4, C) 95% Ar, 4.7% CO_2 and 0.3% Freon.

PERFORMANCE

The sensitivity of an ion chamber is proportional to the amount of gas between the electrodes. Because of the small volume of the tubes, signal levels of fast ion chambers used with wire scanners are only a few millivolts, and these levels depend heavily on the location of the ion chamber. Calculations indicate that multiple scattering of electrons off the wire scanner wire produce most of the signal.[3] Ray tracings on scale drawings have been helpful in selecting locations for these ion chambers. For a 1GeV beam, an ion chamber is installed about 7m downstream of its wire scanner.

Locating fast ion chambers for primary beam collimators presents no problem. Because of the large amount of radiation, signals in the hundreds of millivolts are obtained by placing the ion chamber a few meters downstream of the device.

OPERATION

Signals from the fast ion chambers are monitored on real time displays (oscilloscopes) and/or fed into ADCs (Analog Digital Converter) to calculate beam sizes and monitor individual bunch losses over longer periods of time.

Fast ion chambers used with wire scanners typically have an output of 5mv and need to be amplified. The signal makes a single pass through a LeCroy 612 x10 amplifier before it is fed into an ADC. Fig. 3 shows a wire scanner fast ion chamber setup

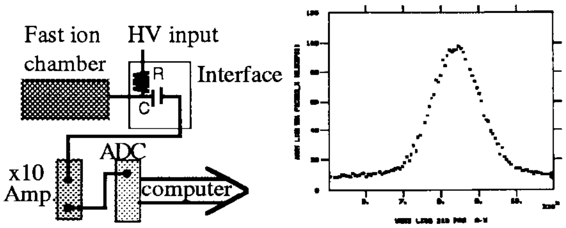

Fig. 3: Block diagram showing basic components of a wire scanner fast ion chamber

LONG ION CHAMBERS

Long ion chambers (PLIC) have been used to locate beam loss and protect the accelerator at SLAC since its beginning.[4] The system consists of a gas dielectric coaxial cable approximately 3500m in length installed on the ceiling of the accelerator housing. Time dispersed PLIC signals travel upstream to the start of the cable. They are reflected, and travel to the downstream end of the cable where they are observed. Because it is viewed from the downstream end of the cable the average PLIC pulse propagates over about 5300m of cable. The rise time of a PLIC signal is distorted by the cable, and this introduces an uncertainty of about 30ns in locating the leading edge of the PLIC pulse.[5]

During the construction of the SLC, PLIC cables were installed in all transport lines.[6] The SLC PLIC signal is viewed from the upstream end of the cable and on average, the signal propagates over only 300m. In this case, the leading edge can be determined to within 5ns.

When the beam path length and the length of the PLIC cable are equal, locating beam losses can be calculated by using an oscilloscope to measure the time from the start of the cable to the leading edge of a PLIC pulse. This interval is the sum of the time it takes the beam to travel from the start of the cable to where the loss occurs and the time for the pulse induced on the cable by the loss, to return to the start of the cable. The SLC PLIC cable has a propagation velocity of 0.914c so:

$$T_{scope} = T_{beam} + T_{beam}/0.914 \qquad (1)$$

where T_{scope} is the time between the start of the cable and the beam loss measured on the scope, and T_{beam} is beam time from the start of the cable to the beam loss.
The beam time between any two events is the time displayed on the scope divided by 2.09.

When there are obstacles and bends in the transport line, the cable length is no longer equal to the distance traveled by the beam, and equation 1 is no longer valid. This path length problem can be reduced by periodically referencing or fiducializing the PLIC signal to a particular beam line component, providing a local reference for beam loss calculations using equation 1. Two methods of fiducializing the PLIC signal, passive and active, have been devised.

A passive fiducial is produced by connecting a 50 or 100ns coil of solid polyethylene coax (which produces no PLIC signal when it is irradiated) between sections of PLIC cable. The notched pulse shown in fig. 4 is produced when sections of PLIC cable with this solid coax between them are irradiated. The thick line indicates the time of a 50ns fiducial cable. The leading edge of the second pulse (indicated by the second cursor) is produced by the end of the PLIC cable connected to the downstream end of the fiducial cable. From this known edge, the time or position of other losses can be measured.

Two discrete losses are unresolved when the time between the losses is less than the decay time of the PLIC signal from the first loss. The second loss can be resolved by inserting a fiducial cable in the PLIC cable just upstream of the second loss. The fiducial cable provides the extra time needed to allow the PLIC signal from the first loss to die away.

An active fiducial can be produced by installing a coaxial switch between sections of PLIC cable. When the switch is opened, pulses, created from earlier beam losses that propagate in the same direction as the beam, reflect off the open switch, producing an inflection in the PLIC signal at the switch's location. Because these pulses do not travel at the same speed as the beam, there must be beam loss at the switch's location in order for the spike to accurately indicate the position of the switch. This effect is shown in fig. 5.

CONCLUSION

Fast ion chambers provide beam loss information, both real time, and computer processed for each of the three SLC bunches. Accelerator operators monitor the real time signals to help them diagnose problems in machine performance. The processed information is used to determine beam sizes and emittances. This information is also stored so that individual bunch beam loss variations can checked for correlations with data from SLC subsystems to identify system failures.

Beam losses in SLC transport lines are located with greater accuracy when fiducials in the PLIC signal, produced by delay cables or coaxial switches, are used as references for beam loss calculations.

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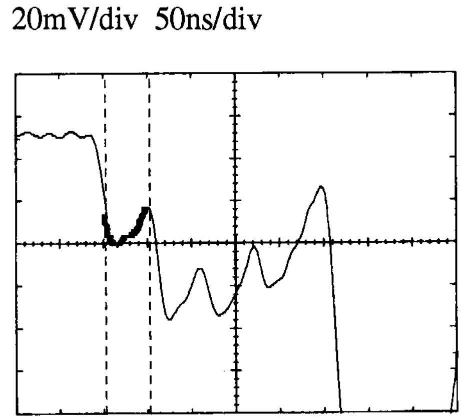

Fig. 4: SLC PLIC. Cursors indicate a notch in the PLIC signal produced by a 50 ns fiducial cable. The two notches to the right of the first are also produced by fiducial cables.

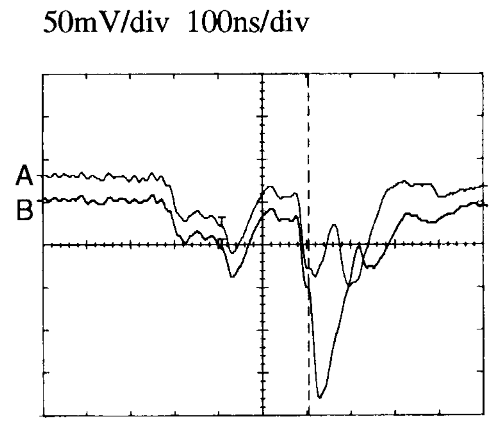

Fig. 5: SLC PLIC signals: Trace A, PLIC switch closed. Trace B, PLIC switch opened. The cursor indicates the position of the switch.

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