Loss Monitors for the Fermilab Linac

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Abstract

A system of beam-loss monitors has been installed in the FNAL 200-MeV linac. It consists of two-foot long ion chambers installed two per tank and six in the 200-MeV diagnostics area. The loss data are available in the main control room via computer and as real time video signals. A high gain amplifier is required for those monitors near the linac cavities because of the normally low losses. System description results of performance tests and examples of monitor use as a tool to assist in linac tuning are presented.

Introduction

The Fermilab 200-MeV linac has used beam-loss monitoring only occasionally since operation began in 1970. Scintillation-photomultiplier detectors were used during initial operation particularly at the higher energies. Ion chambers of the Hornstra design, which are used in the switchyard areas of the main accelerator, have been used on occasion in the linac 200-MeV beam switching area during the past few years and are now distributed along the linac as well. There has never been an essential need for loss monitoring along the linac itself. Residual radiation levels are typically difficult to detect outside the tanks with a standard survey meter, except at two places. One area is the bending magnet region of the cancer therapy transport line for 66-MeV beam where 100 mr on contact is typical. The other point is the straight section between tanks 8 and 9 where a pipe kink sometimes scrapes beam and yields a few mr of residual radiation. The advantage of a more extensive loss monitor system, for use in beam tuning and safety, nevertheless, has long been recognized. For the past two years work on an ion chamber system has proceeded on a very low priority basis because of manpower and money constraints. The detector system is now installed and working quite well although some work remains to be done.

The linac, which accelerated high peak current proton beams until late in 1977 and much lower current (20-45 mA) H^- beams since then, delivers time average H^- beam at 66 MeV of $\lesssim 35\mu A$ to produce neutrons for cancer therapy. The 200-MeV H^- beam required for the high energy physics program is less than half as much.

Detector Description and Distribution

The ion chamber is constructed of a two-foot length of 1-5/8-inch RG319 A/U Andrew Heliax cable, which is placed inside a length of conduit. The conduit is connected electrically to the ground of the power supply which supplies a negative high voltage to the outer conductor of the cable. The center conductor of the cable collects the ionization electrons. The chamber is sealed at the end with PVC gas caps. One end cap is fitted with a high voltage connector and a twinax signal connector. The other supports two gas-line connectors. A standard gas mixture of 95% argon and 5% CO_2 flows through the ion chambers in series. A low flow rate purges the chambers of impurities in a few hours. A brass flow restrictor is placed at the intake of the first chamber to restrict flow. The chambers are operated near atmospheric pressure with a gas flow rate of about 10 cc/min.

Because these chambers are small, they are handicapped by not having the same response for beam loss occurring at different spots along a linac tank. This contrasts with the response of the long ion chambers used at the Brookhaven linac. Having a limited number of "point-like" detectors we decided to distribute them two per tank with both located in the straight section between tanks. They lie in a vertical plane perpendicular to the beam line and parallel to the floor at distances of 5 in. and 32.25 in. above the beam-center line. In this way, although signal strength varies markedly with position of beam loss, the ratio of response of the two detectors is different for nearby versus distant beam loss and yields some information on beam loss location.

Six detectors in the 200-MeV transport area were placed at critical places near diagnostic and beam switching elements.

Electronics and Detector Testing

The amplifier is a high gain, two-stage, two-channel, differential amplifier with built in sample and hold circuits and power supply regulators. The schematic for one channel is shown in Fig. 1. The two 45J stages have a total gain in excess of 3000. The NC260 has a gain of one and serves as a line driver. The 50 ohm resistor in the output of the NC260 coupled with the 50 ohm termination in the control room reduces the ringing occasioned by driving a long cable and reduces the effective gain to approximately 1500. The hold pulse for the Harris 2425 sample and hold circuit is developed by a T.I. 74122, which is triggered by the linac TDATA timing pulse. Power is provided by an external ±20-volt power supply and regulated to ±15 volts by regulators on the amplifier board. The video output pulse is displayed in the control room while the held output via the computer enables plots of beam-loss signal vs. any controllable linac parameter.

*Operated by the Universities Research Association under contract with the U.S. Department of Energy.

Because of the high level of rf noise in the linac tunnel, several steps are taken to minimize its effect. A short length of twinax cable runs between the detector and the amplifier, which , for protection against radiation damage, is placed about 15 feet away in a penetration in the shielding wall. Several layers of aluminum foil are wrapped around the detector and grounded at the linac tank. The on-board regulators are preceded by an rf trap. The amplifier is enclosed in a two-wide NIM module which has all joints and openings covered with conductive tape. As a result, high frequency noise levels observed in the main control room at present are in the 5-30 mV range, typically 10 mV.

Gain curves for the amplifier are shown in Figure 2 and are similar at 10 and 100 kHz.

The response of the ion chamber to beam-loss radiation as a function of applied voltage reaches a plateau above 160 volts at atmospheric pressure as shown in Figure 3. The curve was extended to 1500 volts because some testing was done at higher voltages to give increased, though distorted signals when the chamber contained air. The A-CO_2 gas mixture gives a "gain" in signal of 8.

Figure 4 gives the beam loss pulse response of two detector and amplifier channels with differing amounts of loss signals, noise levels and ringing conditions. The time-scan plots from the sample and hold circuits show the variations over very many beam pulses. Beam pulses were short (10 μs) during tests to limit integrated beam loss.

Beam-Loss Testing

Creation of a few mA of beam loss for testing was caused by misadjusting quads near the entrance and exit of individual tanks, by turning off quads in the mid-tank region and by changing steering coil settings. Loss occurring at unknown and distributed locations in a tank makes it difficult to obtain precise calibrations of localized detectors. Losses were created for beam energies from 66 MeV (Tank 3) to 200 MeV (Tank 9). We do not plot an energy-response curve because of uncertainties, however, monitor signals varied from tenths of a volt per mA loss at 66 MeV to a few volts per mA loss at 200-MeV, a variation consistent with the nice energy-response curve obtained at Brookhaven with long loss monitors.

To test the loss monitors and to measure the distribution of radiation flux in a vertical plane, we placed a bank of six parallel detectors in a vertical plane perpendicular to the beam line at distances of from 3 to 32 in. from the beam line. This was done at the high end of tank 5 and again at the high end of tank 8. Losses were created near the high energy end of the tanks and also further upstream in the same tank. Uniformity of detector response was confirmed by interchange of positions.

Examples of a few flux distribution curves are shown in Figure 5. One sees the quite steep decrease with distance from the beam line when beam loss is known to occur near the detectors. By contrast one sees the slower decrease (in some cases linear) for attempted loss far upstream. The calculated dashed curves are for an assumed point loss in the straight section below the bank of detectors and an inverse square law decrease in the vertical plane. Integration over the detector length was performed but no correction was made for the finite chamber diameter. In other examples in the high energy end of the linac where there is pronounced forward peaking of neutrons, loss created at the input end of a tank was observed to give low but nearly identical signals at the high end of the tank in detectors separated by a distance of 27 in. These results are not unexpected and exhibit some advantage in using two separated detectors in each straight section.

After distribution of the loss monitors throughout the linac, some useful observations have been made in tuning linac parameters. As examples of loss monitor use, plots are shown in Figure 6 for beam loss as a function of a single quadrupole current. One curve shows a loss minimum while the second curve shows a window outside of which losses appear. As expected the on-set of loss occurs long before the beam-current monitors can show the loss. Similar plots have been obtained by adjusting other linac parameters. There is considerable variation in the width of the loss-free window when intertank rf phases are adjusted. Further study of this situation may prove useful.

Reduction of losses in the 200-MeV diagnostic and beam switching area was quickly made by adjustment of linac focusing and steering magnets. Small vertical beam-loss signals between tanks 8 and 9 could easily be removed but would return when automatic steering adjustments were made to achieve a proper match to the booster transport line. This impasse points to the need for either a change in the match requirements or further upstream steering adjustments. Tune up of the cancer therapy beam line routinely includes reference to the beam-loss monitor placed along the line.

As with many other linac parameters which are continuously monitored by the computer, the beam-loss signal can be used to inhibit linac beam when the loss exceeds some preselected level.

The present loss monitors are an aid to linac tuning. We are considering the addition of long loss monitors, particularly along the lower energy tanks where sensitivity is low. There is one long loss monitor under test at present, which will be used at tank 3.

Acknowledgement

The authors gratefully acknowledge the advice on construction of the ion chambers by Rick Janes of the Fermilab Switchyard Group, based on his early experience with similar chambers.

References

1. J. Balsamo, N.M. Fewell, J.D. Klein and R.L. Witkover, IEEE Trans. Nucl. Sci. NS-24, 3, 1807-9 (1977).

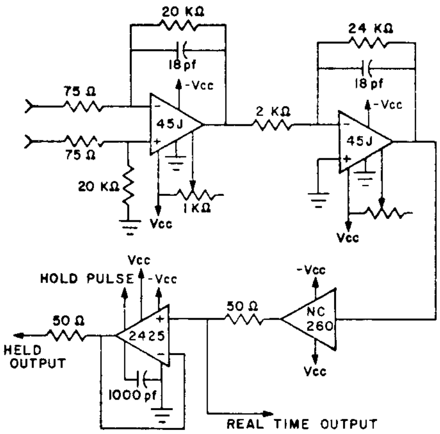


Fig. 1 Amplifier schematic

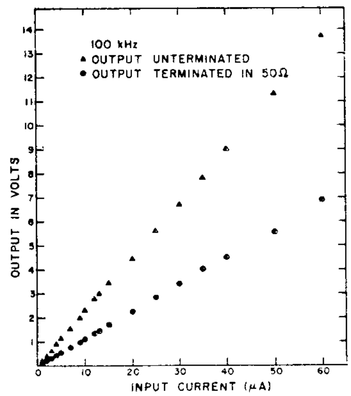


Fig. 2 Amplifier gain curve

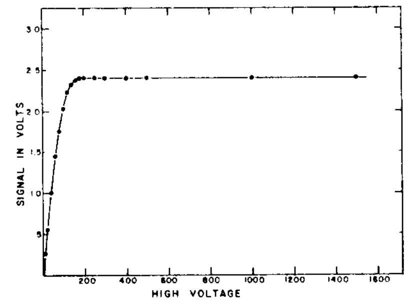
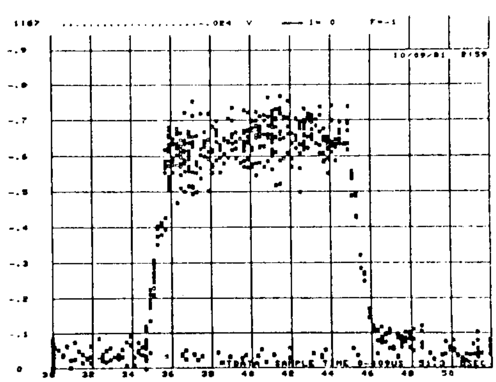
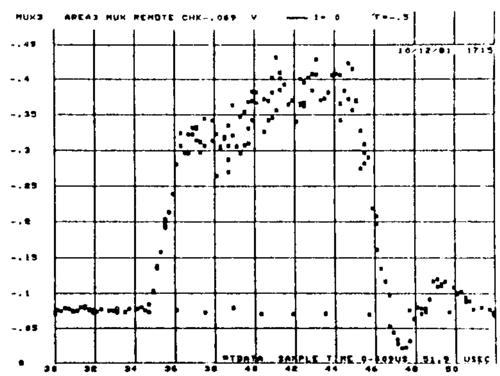


Fig. 3 Ion chamber plus amplifier response versus applied chamber voltage

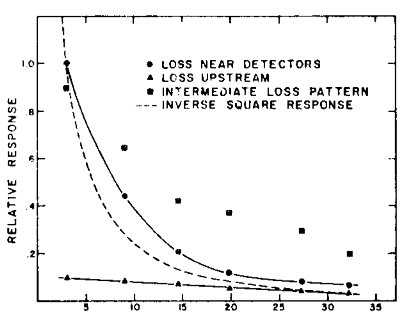


a



b

Fig. 4 Beam pulse loss signals - 2 μs/div.
a. 0.1 volt/div.; b. 0.05 volt/div.



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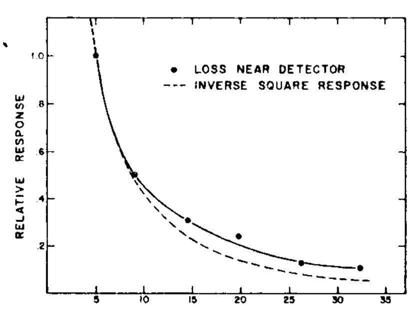
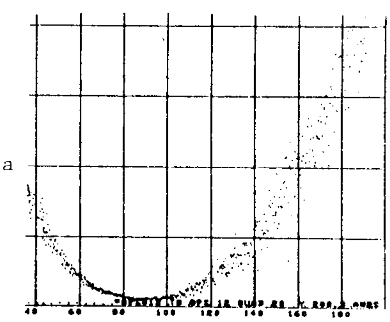


b

Fig. 5 Radiation flux distribution above beam line.
a. 116 MeV; b. 181 MeV

a



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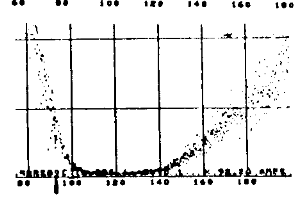

Fig. 6 Beam loss signal versus quadrupole setting in linac tank 8. Scales are 1 volt/div. and 20 amps/div. a. Input quad varied; b. Next to last quad varied.