LONG RADIATION DETECTOR SYSTEM FOR BEAM LOSS MONITORING*

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Summary

This paper describes the Long Radiation Monitor (LRM) system installed at the 200 MeV linac at Brookhaven National Laboratory. This system allows observation of both the spatial and temporal character of the losses in the linac and its transport lines. An array of large diameter gas filled coaxial cables are used as extended ion chambers to detect the losses. The output signals are available as a histogram, video waveforms, and numerical data via the computer. A fast beam interrupt is also provided. The detector characteristics and details of the processing electronics are presented. Results of studies of longitudinal, steering and focusing losses are described.

Introduction

The BNL 200-MeV linac serves as the injector for the AGS and as the proton source for the Brookhaven Linac Isotope Producer (BLIP) facility and the BNL Medical irradiation line. The average current for this machine runs 75 to 100 nA at 200 MeV. This makes it imperative that normal running losses be kept low to reduce long term damage and that large current losses due to missetting or malfunction which would cause immediate damage, are kept to short duration by rapidly interrupting the beam.

There is now growing interest in a new generation of linacs for applications in the energy research area. These would be in the 100 nA (average) range at an energy of 1 GeV. Clearly losses of even 1% for such a machine would be more current than the average accelerated by the present machine! Thus, a detector sensitive enough to observe microampere losses anywhere in the beam tunnel is a necessity for present and future accelerators.

Radiation detectors which have been used in proton linacs in the past, have been localized ion chambers¹ or scintillator-photomultipliers.² These both suffer from the $1/R^2$ dependence of a small detector in observing a loss upstream or downstream of the device. In addition, the small size of the ion chamber limits its sensitivity, while, the scintillator-photomultiplier is subject to serious degradation due to radiation darkening, and, each must have an independent voltage supply to balance the gain variations.

The SLAC electron linac was the first to make use of a long ion chamber³ made of hollow coax, covering the entire length of the machine. They took advantage of the two-mile length of the machine and the fact that the pulse width was short compared to the transit time in the cable, to localize the point of ionization along the detector by measuring the time of arrival at the viewing point. The long cable had the advantage of covering the entire length of the machine without the $1/R^2$ limitation of short detectors. While this was a particularly well suited technique for their electron linac, it could not be applied to a subrelativistic proton linac in which the velocity scale is nonlinear with distance and the pulse length is long compared to the transit time.

At FNAL, Hornstra⁴ used a long radiation monitor-

ing cable which he was able to calibrate directly to read percent beam loss. This made a powerful tool with which to tune the beam lines and minimize losses, but it did not provide spatial localization of the losses.

The present approach makes use of the extended ion chamber formed by a large diameter hollow coaxial cable to provide both spatial and temporal information of the losses in the BNL linac and its transport lines.

System Description

The system consists of 32 long detectors that are uniform in length and where practical are spaced a uniform distance from the beam centerline. The position of each detector is shown on Fig. 1. The signals from these detectors are amplified and the individual video signals are obtainable via a computer controlled multiplex system. The video signals are also compared with individually preset strobed reference levels which can cause the beam to be inhibited by the F.B.I. (Fast Beam Interrupt) system. A histogram of the loss detector output is also generated and these levels can be read on command into the computer. A schematic of the system is given in Fig. 2.

Detectors

The detectors are 25 ft (linac tanks) or 30 ft (transport area) lengths of standard 7/8" air dielectric coaxial cable (Heliex LJS-50) manufactured by the Andrew Corporation. This cable has a solid corrugated aluminum outer conductor and a bare copper inner conductor that is supported by a spiral of polyethylene. One end is sealed by a standard pressurization fitting and the signal is taken from the other end via a standard type N connector that also serves as a gas seal and input. Both of these fittings are supplied by the Andrew Corporation. The detectors are mounted along the cable trays that run the length of the linac and transport system, they are insulated from the trays by a polyethylene jacket that covers the cable. The detectors are approximately 10 ft from the centerline of the tanks and 5 ft from the centerline of the most of the transport line.

Argon gas is fed via 1/4 dia. polyethylene hose to the type N of the first detector and from its pressurization fitting to the type N of the next detector and so on for the 32 detectors. The daisy chain is completed by returning the hose from the last detector back to the gas control panel. At this panel, input and output pressures are monitored and fault conditions are transmitted to the control room. The system automatically switches to a reserve tank if the gas supply is low.

Initial Testing

Tests were performed on a 22 ft sample cable located in the 200 MeV transport area to determine its characteristics and practicality as a loss detector. Voltage and gas pressure sensitivity measurements were made; the results are shown in Fig. 3. The signal was found to increase linearly with pressure in the range 0 to +30 lb/in.². To keep well within the pressurization of the cable fittings, the operational working pressure was chosen as 10 lb/sq. in. At this pressure, the signal output reaches a plateau at a bias voltage of about +100 V. Below +50 V the signal falls off rapidly and

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the pulse shape becomes distorted. Tests on this cable were made to determine the choice of coupling capacitor and load resistor. A compromise was made on the load resistor between signal strength and rise time; 500 Ω was chosen giving a time constant of 18 μ sec for the longest signal return cable (1200 ft). This will be reduced by a factor of 10 in the future since operating experience has shown the transport area detectors are too sensitive. A charging resistor of 1 M Ω and a coupling capacitor of 0.22 μ F was sufficient to prevent differentiation of the signal. Further tests at tank 3 (66 MeV) and tank 9 (200 MeV) showed that these detectors are indeed practical in the tank area and a full system was then built and installed.

Electronics

Initially each detector had both a bias and signal cable that ran back to the electronics situated in the linac control room. The signal was capacitively coupled and amplified with a gain of 100. This was satisfactory for the 200 MeV transport area where the signal strength was high, since the radiation is not shielded by the tank walls, however, in the tank area additional amplification was required. To improve the signal to noise ratio and to remove ground loops caused by the two cable system, head amplifiers were installed in the tank area and the same cable was used for the bias voltage and signal return on each detector. With this system noise free signals are obtained, Fig. 4.

The tank area head amplifiers have a gain of 15 and are installed at the detector. Signals from these and the transport area detectors are coupled via two distribution panels to four 8-channel radiation level-detector modules. Here the signals are amplified with a gain of 100 and compared with strobed reference levels that can be individually set. The comparator outputs are fed to R/S latches which are reset each machine pulse. All the R/S latches are "or" ed into the F.B.I. system which inhibits the beam if a radiation signal greater than any trip point occurs. The individual R/S latch outputs are also brought out to the loss monitor panel (Fig. 1) to give an indication of where the loss occurred.

The individual video signals are also brought out to two 16-channel multiplex units. These are dual units and any two detector video signals may be selected at the same time via the computer.

The 32 individual video signals are also connected to two 16-channel sample and hold modules. Here the signals are fed via FET's to storage capacitors. The FET's are all opened at the same time by the master sample pulse, which can be selected at any time during the beam pulse.

The charge on the 32 storage capacitors is then multiplexed out by the 32 channel charge transfer multiplexer. The multiplexed output is buffered and supplies a histogram display of the radiation system. The output is also digitized and stored in a local memory on the scanner control card from where it can be read into the computer on command.

Detector Calibration

To calibrate the detector system the input quadrupole of each tank was misadjusted to cause a given loss (4 mA) in that tank and the signal from the radiation monitors noted. Misadjustment of the input quadrupole was sufficient to cause the required loss, however, the location in the tank at which this loss occurred could not be selected. Therefore the energy at which the loss occurred was only known to be between

the input and output energy of the tank. As there are two monitors per tank the signals from these were summed and plotted against the tank number (Fig. 5). On this graph is also plotted a curve of total neutron yield per proton stopping in copper⁵ versus tank input energy. The measured loss points follow the slope of this curve reasonably well. It should be noted that these measurements were taken without the head amplifiers and therefore the voltage scale should be multiplied by a factor of 15 for the present system.

In the beam transport area the signals from the radiation system cause the input amplifiers to go into saturation before a beam loss observable with the beam transformer system can be made.

Radiation Detection

Tests were made to determine how well the loss pattern observed at the radial location of the cable correlated with that at the rf cavity. An array of pocket "self-reading" dosimeters and film badge packs were exposed along the cable at tanks 3 and 9. In the test at 66 MeV it was found that approximately 1100 microcoulombs loss resulted in an average γ exposure of 150 mr along the cable. At tank 9 (200 MeV) the same test resulted in an average γ exposure of about 400 mr. At tank 3 the neutron dose as determined by the NTA film was an average of 1 rem while at 200 MeV an average of 5 rem was found. In both exposures the detailed pattern of the radiation at the cable closely matched measurements made of activation at the outer wall of the cavity, indicating that the cable does observe the real character of the losses.

Operating Experience

In the six months that the radiation cables have been installed they have played an important role in reducing losses and increasing beam to the AGS. The system has proved useful in tuning to reduce losses, monitoring to prevent missteering and interlocking to prevent catastrophic beam loss.

Tests were made at various tanks to determine the loss patterns observed for different loss producing mechanisms. Transverse losses were caused by misadjusting a pair of quadrupoles in a given tank. Unfortunately steering dipoles were only installed at the end of tank 3 so this method of producing loss was limited. It was found that the pattern of losses shown by the cables varied from tank-to-tank and in one case, upon whether the quadrupole current was too high or too low. In some cases the losses were found to be localized while in others a periodicity resulted which followed the betatron wavelength. This unpredictable behavior is believed due to the missteering known to exist in the linac.

When longitudinal errors were introduced by mis-setting the rf phases or amplitudes, the losses appeared on several cables immediately downstream of the error, since there is only a fractional phase oscillation per tank after tank 4.

Another means of observing rf induced losses is with the video waveforms from the detectors. The rf systems are servo-controlled to the desired operating point. Since the beam represents a step function perturbation of the rf system, if it is not tuned properly a damped oscillation occurs which will modulate the beam energy. This reveals itself by causing loss patterns which vary in time and the offending rf system may then be found.

After the system was completely installed, it was

used to tune the linac for minimum signals on all detectors. While it was not possible to see any significant current increase on the output beam transformer of any individual cavity, when the tuning process was completed the final transformer at tank 9 read several mA higher than at the start.

After the tuning process was completed, the signal at the low energy end of tank 9 still read 1 volt (50 μ A loss) but all others were less than 0.5 volts. The loss comparators for all channels were set arbitrarily at 2.0 volts. This resulted in a non-uniform trip sensitivity due to the energy dependence of the radiation. In the transport region the sensitivity is so high that no convenient means of producing a small known loss was found. However, by reducing the gain it was estimated that the sensitivity was less than 10 μ A loss per volt of signal. This has proved inconvenient since it is impossible to run a 2 mil diameter tungsten wire profile monitor⁶ through the beam without tripping the beam interrupt.

Conclusions

A system for monitoring radiation due to beam loss has been developed for the proton linac. This system effectively locates the point of loss and provides a fast beam interrupt to prevent damage. The detectors are sensitive along the entire length of the machine and its transport lines. The sensitivity is more than adequate for existing average current machines and shows promise for projected linac designs at high average current.

The existing system has been effective in reducing machine activation since its installation and has contributed to the higher current output and operating efficiency achieved recently by the linac.

References

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Figure Captions

- Fig. 1 Radiation monitor distribution.
- Fig. 2 System diagram.
- Fig. 3 Signal sensitivity versus pressure and bias voltage.
- Fig. 4 Typical video pulse: Tank 4, 2V/div, 50 μ sec/div.
- Fig. 5 Signal versus tank input energy.