IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

IMPROVED FNAL LINAC BEAM CHOPPERS

K. Bourkland, C. Curtis, G. Lee and G. Tool
Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, Illinois 60510

Abstract

The Fermilab Linac uses two electrostatic beam deflection systems as beam choppers, a 750-keV system located between the ion source and the input to the Linac and a 200-MeV system at the output of the Linac. This paper discusses the 750-keV chopper experience with both proton and negative ion beams and the ability of these systems to tailor the Linac beam to the diverse requirements of its users; normal accelerator injection, neutron therapy beam, and electron cooling experiments. This flexibility plus a cleaner beam pulse, improved thyratron operation, and mechanical modularity are the results of recent improvements. Additional benefits have been increased reliability and ease of service to the 750-keV chopper.

Introduction

Over the past decade the beam pulse from the Fermilab 200-MeV proton linac has been controlled by two electrostatic beam choppers. The length of pulse accelerated in the linac, which varies from 1 to 65 µs, is determined by a chopper in the 750-keV transport line. The length of the pulse for injection into the booster synchrotron is determined by a chopper in the 200-MeV transport line. In the early days a 750-keV chopper was not essential to operation and was not used initially. Rise time of the beam pulse, typically 5-10 µs from the duoplasmatron ion source, was reduced to < 1µs by pulsing the bias voltage on a plasma expansion cup.[1] A true beam chopper, independent of the ion source, was nevertheless desirable to improve rise and fall times and to provide more flexibility of operation. The need became greater as more uses for the linac beam on a time-sharing basis developed. These uses included normal high energy physics operation with variable beam intensity, neutron therapy for cancer patients, proton radiography and beam cooling experiments in a small proton storage ring.

The basic 750-keV beam chopper consists of two parallel plates of one-foot length and three-inch separation, to which are applied dc voltages up to 30 kV, and a charging and switching circuit using 40-kV English Electric CX1154 thyratrons (see Fig. 1). Initially one plate is at positive high voltage while the other is at ground. A pulse of beam that passes between the plates is deflected into a beam stop until such time as the ON thyratron is fired thereby dropping the charged plate to low voltage (<100V) and permitting beam to pass on to the linac. At a later time the beam is again deflected by firing the OFF thyratron thereby taking the other plate to a negative high voltage and again deflecting the beam into a beam stop. The thyratrons extinguish when the conduction currents fall to a sufficiently low value, after which the capacitors again charge up to be ready for the next beam pulse 1/15th s later.

The 200-MeV beam chopper operates on a similar principle at a higher voltage with the difference of having to provide a transmitted beam which is deflected or switched into another line. The starting configuration is therefore with both electrodes at the same high voltage.

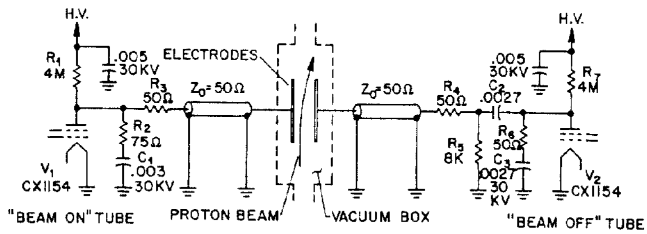


FIGURE 1. Original basic circuit as modified.

As requirements on 750-keV chopper use increased, a decision was made to improve the original system coincident with the conversion to H^--ion source operation. The old system, while adequate for high energy physics operation, had several deficiencies, especially in relation to multiple uses of the linac beam.

System Problems

The source of the system problems was both electrical and mechanical in nature. To understand these deficiencies we refer to the circuit, Figure 1, of the original chopper as developed in the early days and its configuration as shown in Figure 2. To build a working chopper in minimum time, the designer accomodated many compromises in the packaging of this system. Shown not too clearly in Figure 2 is one of the coaxial output cables connecting the electronics enclosure to the vacuum feed-thrus leading to the deflection electrodes.

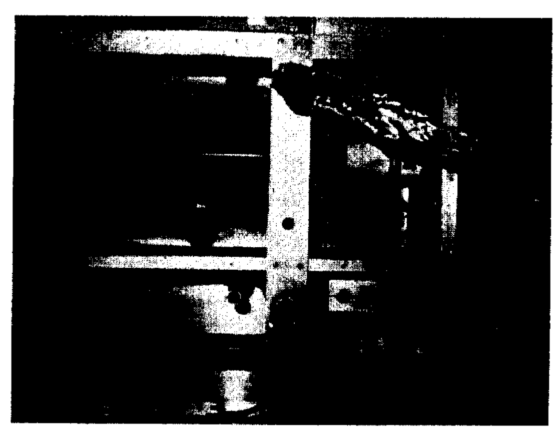


FIGURE 2. Original circuit assembly.

The aluminum enclosure with its poorly made joints was at least partially responsible as was the EMI from the output cables, in spite of their coaxial construction and additional shielding, for the cross-talk triggering that occurred between the ON and OFF channels. This led eventually to abandonment of

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

0018-9499/81/0600-2994$00.75©1981 IEEE

the OFF channel and the grounding of the OFF electrode. Chopper operation was thus compromised and the width of a "beam chop" was controlled by the trigger time of the ON channel and the turn-off time of the ion source. The less than optimum beam in the tail of the injected pulse could not be deleted.

Other modifications to get by included replacement of the firing circuits, changing of capacitor types to overcome capacitor failures, and reduction in the value of R_2 and R_6, Figure 1, from 8K Ω to 75 Ω to reduce the effects of "beam loading" due to beam interception by the electrode. The latter modification increased the peak current in V_1 from 3.75 A to 400 A and was a contributing factor in the short (∼1 year) lifetime of the thyratrons. Over cooling of the tubes also may have been a factor in reducing tube life.

Beam loading resulted from deflected protons striking the more negative electrode and releasing secondary electrons, which were collected by the more positive electrode. The effect was a few kV of negative and positive voltage changes on the positive and negative electrodes respectively. No such loading enhancement by secondary electrons is possible for negative ion beam deflection.

The New Design

The approach to a new design started with a computer analysis of the old circuit using the SPICE and SCEPTRE programs.[2,3] Refinements to that circuit, shown in Figure 3, improved the pulse characteristics as a result of an improved impedance match between the switch tube circuit and the capacitive electrodes.

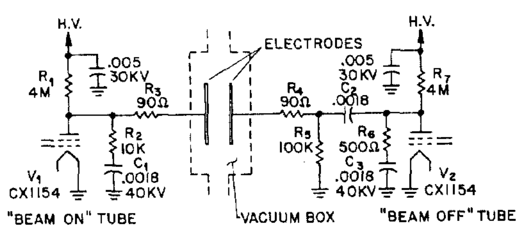


FIGURE 3. Present chopper circuit.

Physically separating the ON and OFF sides of the circuits into individual enclosures and mounting them directly to the vacuum box eliminated the need for coaxial cables, Figures 4 and 6. In retrofitting the original pre-accelerator with a set of the newly designed choppers, it was necessary to include a modified coaxial cable to make the connection since it was not feasible to mount them directly. This modification involved removing the outer jacket of

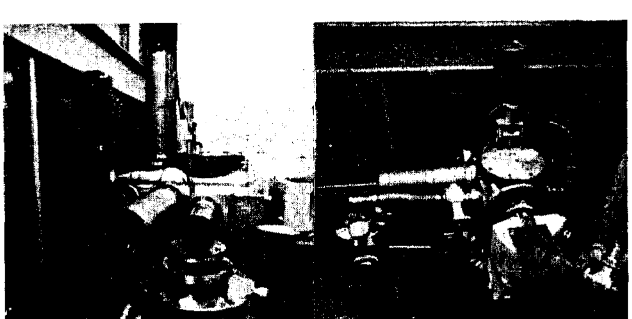


FIGURE 4. Chopper units in preaccelerator beam line.

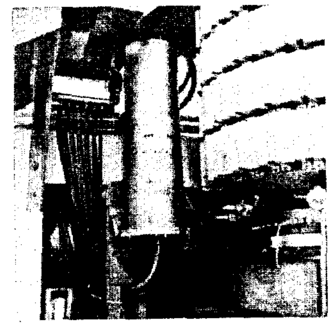


FIGURE 5. Chopper unit in place showing coaxial output cable.

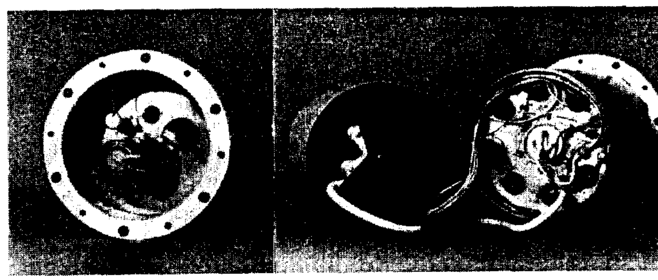


FIGURE 6. Internal views of chopper units.

RG-220 coaxial cable and replacing it with rigid copper tubing to improve shielding, Figure 5. The only coupling remaining between the two channels is the capacitance between the electrodes. Analysis showed the effects of this coupling to be negligible.

Much of the improvement in electrical performance is due to the new package design. Copper was selected as the enclosure material because of its excellent electrical and thermal properties plus the ability to soft solder all critical joints.

These enclosures, shown in Figures 4-6, are made by roll forming .062-inch thick copper sheet stock into 10-inch diameter cylinders. Stacked one atop the other, three compartmented sections complete the structure. A flange welded to the output end of the enclosure matches that of the vacuum box and serves as the sole means of mounting the units. This output section contains the CX 1154 thyratron and, on an interchangeable subchassis, the high voltage output components. Evenly distributed around its circumference are cooling-air inlet holes aligned to the cathode and first grid sections of the thyratron. Since no appreciable anode heating occurs, no cooling air is directed at that level. Contained in the center section is the 4-megohm charging resistor while the topmost section houses the trigger circuit, a 35 CFM exhaust fan, and the power supply connectors. The spatial distribution of these components in the enclosure is shown in Figure 7. All power to the units is supplied via cables from power supplies located in the linac equipment gallery.

With this simplified mounting scheme and the use of interchangeable subchassis, a single spare unit can fill either socket position in the event of equipment failure. Changing a unit can be accomplished in 10-15 minutes and a failed unit repaired later.

A similar packaging structure has been designed

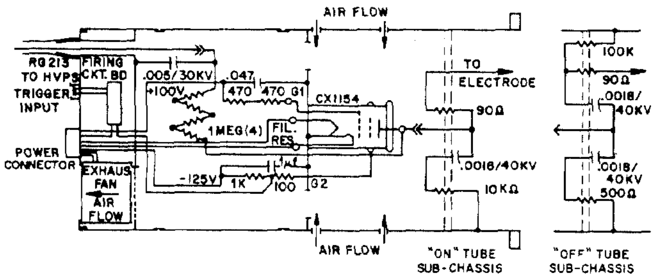


FIGURE 7. Layout of components.

and is under construction for the higher voltage 200-MeV chopper.

Performance

Since the installation of the first redesigned chopper system in 1977 for use on H^- beams, operation has been stable and satisfactory with no loss of capacitors or thyratrons. The R_1 resistor was replaced once because of corona damage and corona shields were added near the end caps. There was one other failure because of insufficient insulation on a high voltage lead. There is a chopper in each of two 750-keV H^- -beam lines. One operates with a high voltage of 20 kV, the other at 26 kV because of a difference in downstream beam-line geometry. A maximum droop of 1 kV on the positive electrode has been observed during deflection of a 50-mA H^- beam for 30 μs when using the R and C values of Figure 3. Voltage switching times are observed to be $\sim$20 ns. The programmable and adjustable chop widths serve all users very well and no beam loading problems result from variation of chop timing during the beam pulse.

Examples of voltage waveforms on the deflection electrodes are shown in Figures 8 and 9.

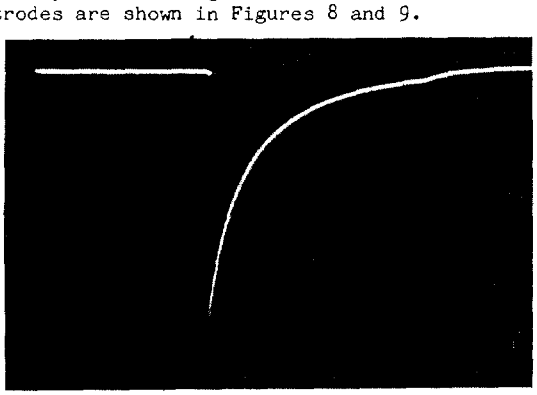
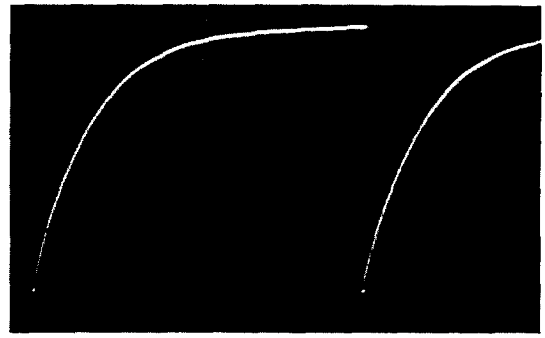
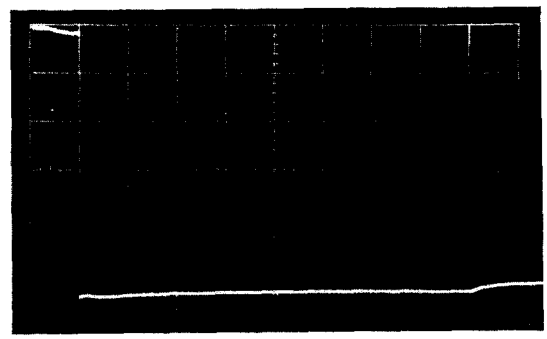


FIGURE 8. Electrode voltage for OFF tube. 5kV and 200 μs per division.



a. 10 ms per division.



b. 50 μs per division.

FIGURE 9. Electrode voltage for ON tube. 5kV per division.

Acknowledgments

The authors acknowledge the initial design and construction work by Lowell Klaisner and Gerry Ortlieb 10 years ago. The basic design, which has been changed little, served its purpose until greater demands were made including operation with proton currents up to 1/2 ampere. For assistance with construction and testing of the refined system, the work of James Schallenberger is recognized.

References

1. C.D. Curtis et. al., Proc. of 1970 Proton Linear Accelerator Conf., National Accelerator Laboratory, p. 217.

2. E. Cohen, "Program Reference for SPICE 2", University of California, Berkeley, Electronics Research Laboratory Document M592.

3. S.R. Sedore, J.R. Sents, "SCEPTRE SUPPORT II, Volume I, Revised User's Manual", Air Force Weapons Laboratory Technical Report No. AFWL-TR-69-77, Vol. I.