OPERATION OF THE BROOKHAVEN 200-MeV LINAC*

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Introduction

At the last Linear Accelerator Conference held at Chalk River, Kenneth Batchelor[1] reported on the first five years of operations of the BNL 200-MeV linac. This paper describes the recent modifications to the machine and its continued operational status.

Operational Performance

The linac continues to run in a very reliable manner; Fig. 1 shows that the reliability has risen to 95% of the scheduled operating time of approximately 6,000 hrs/year. Machine downtime has stabilized to an average of 250 hrs/year over the past three years. This low figure has been accomplished even though the linac building is manned only during normal working hours. After the normal workday period, the AGS operators, who are remote from the linac building, must diagnose and rectify the fault, or in more complex failures, call in linac personnel.

The linac continues to run at 5 pps, with short runs at 6.7 pps for the Chemistry line; the normal AGS requirement is 1 pulse/2.4 sec. The repetition rate was reduced from 10 pps at the beginning of 1976 due to a series of 60-kV power supply transformer and 12-inch transmission line failures. Running at the lower repetition rate has reduced these failures considerably and although the average current delivered to the BLIP facility was reduced, the total current/year has actually increased. The linac average monthly output current for the past three years is shown in Fig. 2; it can be seen that we now run with a peak intensity of about 60 mA. Prior to September 1978, we had run long periods in excess of 70 mA and at times, 80 mA; however, after running in this manner, we noticed a marked decrease in the life of our RCA 7835 power triodes. (This is discussed later.) The output current of the linac was, therefore, reduced to 60 mA which is sufficient for the AGS to run at 1 x 10^{13} protons/pulse.

System Performance

Rf System

A year-by-year breakdown of system failure is shown in Fig. 3. It can be seen that although the rf system accounts for 50% of the linac downtime, the actual hours of downtime have fallen to an average of 120 hrs/year. Approximately half of this time are minor faults of less than one

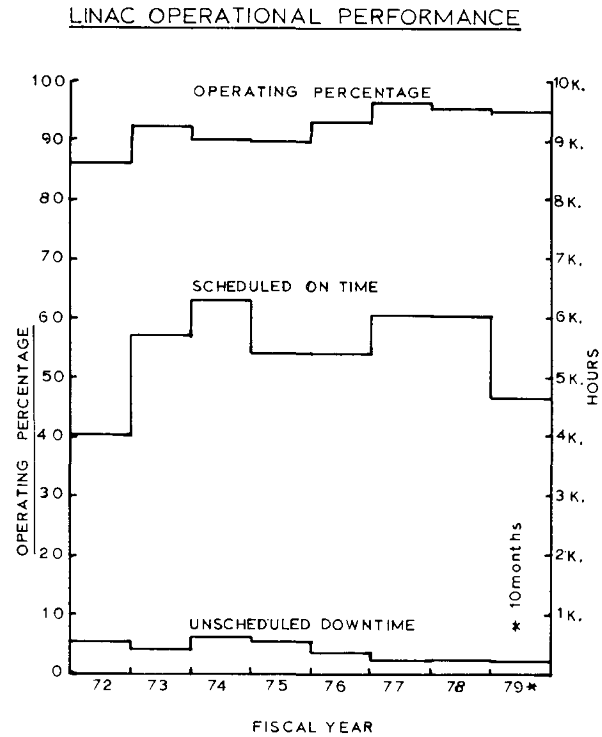

Fig. 1

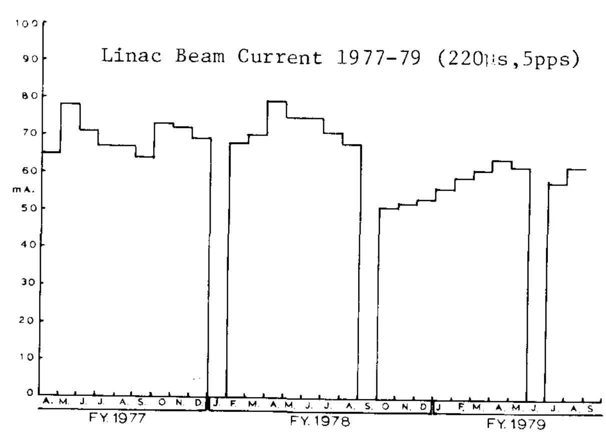

Fig. 2

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hour, such as tuning, etc. On the whole, the rf systems perform very well and it is difficult to pick out an area which could significantly reduce the downtime further.

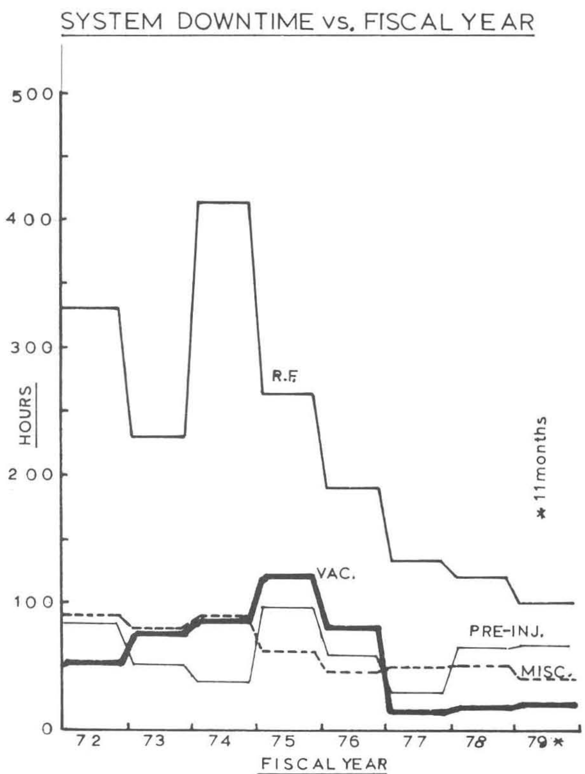

Fig. 3

Vacuum System

The vacuum system, which was the second major contributor to downtime, now only accounts for approximately 20 hrs/year. This improvement is mainly due to the changes in tank monitor probes and BLIP transport line, described by Ken Batchelor at the last Linac Conference, and also due to the long radiation monitoring system[2] that inhibits the beam, if the radiation at any point along the machine exceeds a pre-set limit, i.e., it keeps the machine honest.

Preinjector

Problems with the ion source and the bouncer account for most of the approximately 65 hrs/year of downtime attributed to the preinjector. We went through a period when the source filament life steadily declined and they had to be run at increasingly higher currents to obtain a discharge. Finally after changing the complete source, it was discovered that the source had a minute freon leak. This leak, although difficult to find (10^{-8} mmHg scale) was sufficient to poison the filament. Los Alamos has recently experienced a similar fault.

Leaking oil on the Cockcroft-Walton generator stack led to the discovery of a badly burnt capacitor, Fig. 4. This failure is thought to be due to

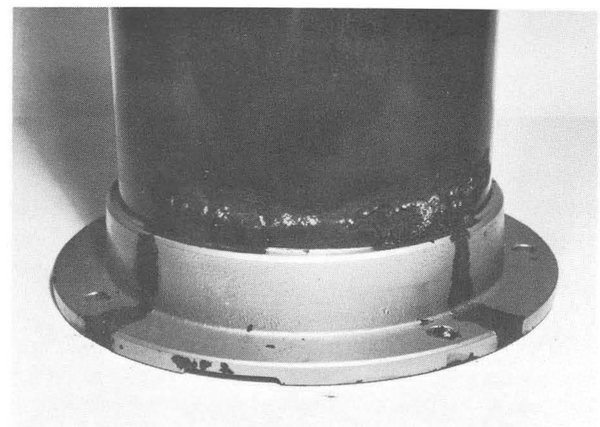

Fig. 4. Damaged Cockcroft-Walton capacitor.

the fact that these capacitors have painted mounting flanges onto which corona shields are clipped. The paint is non-conductive and arcing through the paint due to the ac component between the flange and shield has occurred. It seems that this arcing also occurred from the top of the corona shield through the glass-epoxy case to the capacitor sufficient to burn a large area of the case. Flexible connecting straps have now been connected from the mounting flanges to the corona shields to prevent this from recurring.

More recently, several small vacuum leaks were found around one of the ceramic spacer joints of the high gradient column. These were filled by an epoxy bead applied around the joint while the column was under vacuum. The high voltage was applied two days later and no difficulty was found in conditioning the column.

Miscellaneous Systems

The final 50 hrs/year of downtime is due to the remaining control, quadrupole, water systems etc.; no significant reduction in this downtime is likely.

Machine Modifications and Improvements

Radio Frequency Interference

An off-site complaint of TV reception interference initiated an investigation into the rf radiation from the linac building. The building which houses the rf system is approximately 500 ft long and is clad in aluminum. Field strength measurements outside this building confirmed two radiation lobes of sufficient strength to cause TV interference. Measurements inside the building indicated that the main rf leakage areas were the grid-input sliding section of the 7835 power amplifier, its grid cooling hose and the RCA driver cart. These inside measurements, however, were well below the Federal limit of 2 MW/m^2. Metal braid was placed over the grid cooling hose and metal "top hats" were placed over the input sections of the 7835 cavities, Fig. 5. This resulted in a 22 db decrease in the radiation levels outside the building.

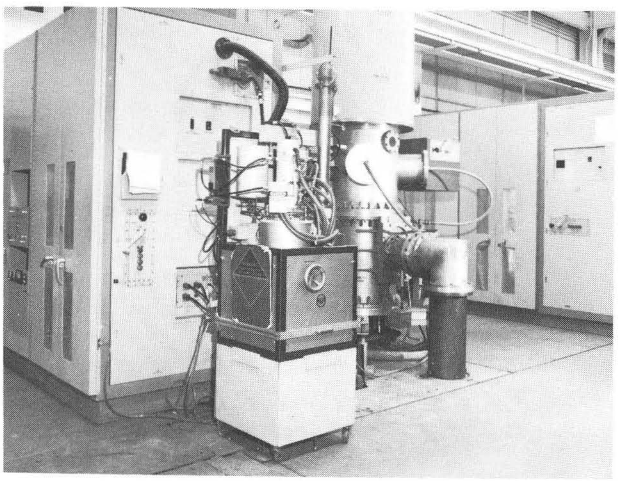

Fig. 5. 7835 power amplifier with RFI shielded input section.

The RCA driver cart is now the major source of RFI. This cart houses a 4616 driver stage with its two 7651 pre-driver stages. In its present form this is very difficult to shield. However, due to the age of the 7651 amplifier cavities and the cost of maintaining them, the first pre-driver stage will be replaced by a 350 W solid-state amplifier stage. This will free up spare units for the second stage and also allow us to remodel the driver cart to allow for RFI shielding.

7835 Tube Life

As has been stated earlier, the linac beam output has been reduced to 60 mA because of the reduction in tube life. At BNL we have accumulated in excess of 500,000 hours of 7835 tube operation. From this operational experience, together with data supplied by RCA, we are able to predict reasonably well the expected filament life of an 7835 tube at BNL. Here we run the filament current just above the emission limiting point that will give the required power output conditions. This power requirement and, therefore, filament current is determined by the accelerating tank powered and the beam accelerated. The large difference in accelerating power requirement shows up a large difference in tube life; this is shown in Fig. 6 where tube life for a number of tubes is plotted against the plate power required. The scatter on the graph is due to incomplete records of linac beam levels and some movement of tubes to different tanks; however, the trend is quite clear.

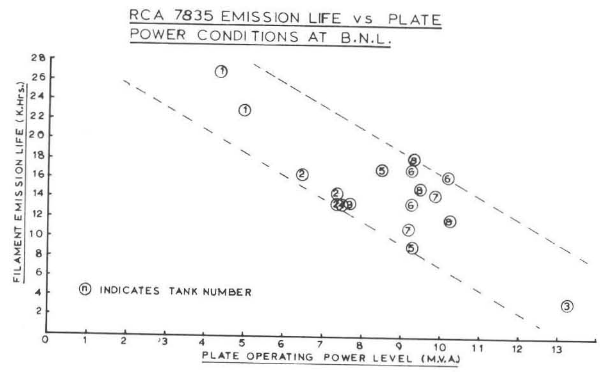

Fig. 6

Measurements of the necessary filament current for various linac beam currents were made on tank #2 which is typical of most of the linac tanks. Calculated filament temperatures for these currents are supplied by RCA[3] and using these temperatures, life expectancy was obtained from a curve by Ayer.[3] These results are plotted in Fig. 7 and are in good agreement with our actual experience.

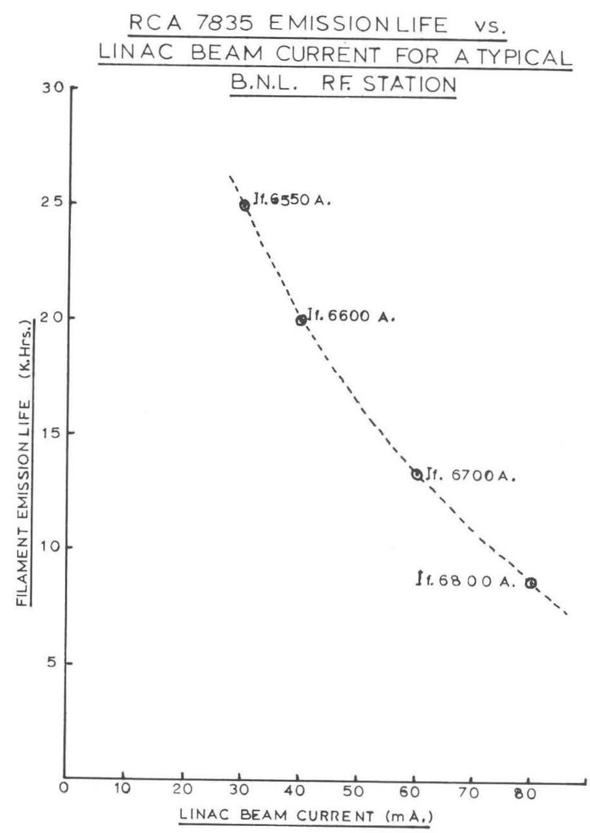

Fig. 7

Rf Phase Control System

The low level phase control system[4] utilizes a number of phase shifters to bring the phase of the rf inputs to the phase servo to within its control range of ±35°. These phase shifters are also used in the phase monitoring systems. Initially these phase shifters were mechanically adjusted with a phase range of 180°. Because of this limited phase range and also because of mechanical problems, these phase shifters were replaced by electronically controlled units having a phase range in excess of 360°. Similar 180° units are now being installed as the controlling element, together with a new control amplifier card, to replace the old phase servo control. By separating the rf signals and control, we have a more stable system with a greater phase range and faster servo time than the old system.

Rf Phase Shifter Design

These phase shifters use the same principles used at the P.L.A. at the Rutherford Laboratory.[5] However, this phase shifter uses strip-line techniques that enable a very compact unit to be made with a large phase range. The 180° units are composed of a 3 db, 90° strip-line coupler with varactor diodes on control ports 2 and 4. The phase change for this type of coupler is equal to the angular change in reflection coefficient at each of the control ports. The varactor diodes used (BB-105A) give a 90° angular change at 200 MHz for a bias change of 0 to 10 V. However, this angular change is increased to 180° at the control port by the use of an intermediate high impedance transmission line of suitable length. With the low dielectric constant strip line board used, the required strip width of this intermediate line would be impractically thin. This was overcome by spiralling the line and removing the ground plane on either side of it.

The 360° units are two 180° units in series printed on one board. The characteristics of these shifters are shown in Table I.

180° Phase Shifter - (D28-ILE-695)

Control Voltage	0 thru 10 Volts
Phase Shift	0 thru 210°
VSWR	1 thru 1.2
Insertion Loss	0.2 thru 0.6 db

TABLE I

Preinjector

As mentioned in the last conference, the old Phillips set has been installed in the second preinjector pit. It has run satisfactorily and the Heavy Ion Fusion Group[6] has accelerated both protons and Xenon using a standard BNL duoplasmatron ion source. After completion of that program, the Linac Group is now preparing the preinjector to accelerate an H^- beam.[7]

Machine Users

Brookhaven Linac Isotope Producer (BLIP)

As mentioned earlier, the average beam current to BLIP was reduced at the beginning of 1976 to increase the reliability of the linac operation. This increase in reliability has made up for the low beam current as is shown in Fig. 8. The total

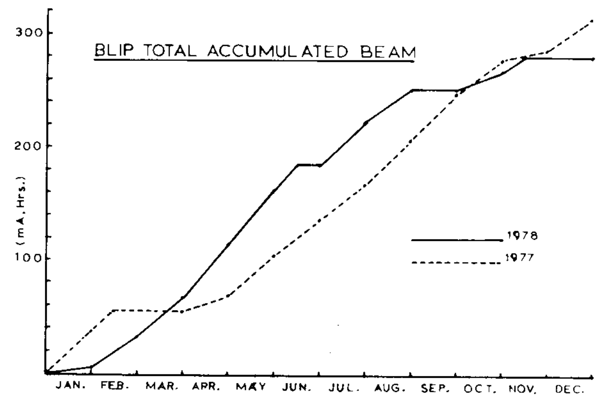

Fig. 8

intergrated beam for 1977 and 1978 was 315 mA hours and 280 mA hours compared with 133 mA hours and 177 mA hours for the previous two years. This is reflected in a production of 34,820 mCi of Xenon-127 in 1978, compared to 5,640 mCi in 1976. This production rate will, however, be somewhat less in the future due to reducing the peak current of the linac to 60 mA.

Chemistry Linac Irradiation Facility (CLIF)

Since the last conference, this beam facility has been renamed, "The Medium Energy Intense Neutron (MEIN) Facility". The MEIN facility produces an intense, energetic beam of neutrons by stopping the 200-MeV proton beam of the linac in a water-cooled copper beam stop. Yields of neutron-deficient isotopes in the product element relative to the desired neutron-rich isotopes can be suppressed by factors of 10 to 100 through the use of these energetic neutrons instead of using protons. Characterization of the decays of new neutron-rich nuclei is thus made possible in spite of their generally short half-lives. Decay scheme information and atomic mass measurements from these studies are useful when applied as checks of current theoretical models for the behavior of nuclei far from stability. It is in this manner that the discovery of ^{196}Os was reported in October 1977.[8]

Brookhaven Proton Bio-Medical Facility

Medical applications of the linac are being developed in a spur beam dedicated to this purpose ("The Brookhaven Proton Bio-Medical Facility").

Three avenues have been pursued to date.

Visualization of the proton beam interaction volume by means of in vivo activation of positron emitters, Oxygen-15 with two minute half-life and Carbon-11 with 20 minute half-life, has been demonstrated.[9] An extension of this technique offers exciting possibilities for quality control in particle beam therapy.

The second application, presently in the planning stage, is "radio-surgery", using the proton beam for ablation of intra-cranial benign tumors. This approach uses multiple beams with different entrance sites, with the Bragg peaks from each beam overlapping at the target volume. This technique produces a nearly ideal concentration of dose at the tumor, while sparing nearby critical organs.

The third application currently being developed is the study of the transport, from a locally irradiated volume, of the positron emitters produced by the beam interaction in tissue.[10] The Oxygen-15 generated is principally bound in water molecules. This labeled water is removed from the beam interaction region by means of perfusion. Information is thus available concerning regional blood flow. The carbon isotope appears to offer similar data about local metabolism. This facility is the only one with a positron camera on-line with a penetrating particle beam.

Conclusions

During the past three years the 200 MeV-linear accelerator has continued to operate at a high level of performance and reliability. The linac output beam current has been limited to 60 mA in order to obtain the maximum rf power tube life without compromising the output performance of the AGS. Despite a reduction in pulse repetition rate, total beam current to the BLIP facility has increased to an average of 300 mA hrs/year.

Acknowledgments

The authors wish to acknowledge the dedicated work of the linac maintenance technicians whose efforts play such an important part in maintaining the excellent record of this machine. The help given by J. Stabley of RCA in understanding the factors governing tube life is also acknowledged.

References

1. K. Batchelor, Linear Accelerator Development at Brookhaven National Laboratory, Proc. 1976 Proton Linear Accel. Conf., Chalk Rover, AECL-5677.
2. J. Balsamo, N.M. Fewell, J.D. Klein, R.L. Witkover, IEEE Trans. Nucl. Sci., NS-24, (3) (1977).
3. Private communication with J.D. Stabley, Power Devices Appl. Eng., Solid State Div., RCA, Lancaster, PA.
4. I. Weitman, Phase Control and Frequency Control of 200 MeV Linac for the AGS, Proc. 1970 Proton Linear Accel. Conf., NAL, Batavia, IL.
5. K. Batchelor and N.M. Fewell, Phase Shifting Using Varactors, Rutherford Laboratory Report, RHEL/R156.
6. R.M. Mobley, A.A. Irani, J-L LeMaire, A.W. Maschke, Neutralization of Positive Particle Beams by Electron Trapping, Proc. Symp. on Production and Neutralization of Negative Hydrogen Ions and Beams, (BNL 50727, Sept. 1977).
7. D.S. Barton and R.L. Witkover, Plans for H^- Acceleration in the AGS Linac (this conf.).
8. P.E. Haustein and E-M Franz, Phys. Rev., C, Vol. 16, No. 4, October 1977.
9. G.W. Bennett, J.O. Archambeau, B.E. Archambeau, J.I. Meltzer and C.L. Wingate, Visualization and Transport of Positron Emission from Proton Emission from Proton Activation in Vivo, Science, Vol. 200, June 9, 1978.
10. C. Duncan and G.W. Bennett, IX Intern'l. Conf. on Brain Metabolism, Tokyo, May 1979.