NEW ENGLAND NUCLEAR CORP. LINEAR ACCELERATOR PROGRESS REPORT

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Summary

The New England Nuclear Corporation's 45 MeV proton linear accelerator has previously been described in detail.[1-6] This report will briefly cover the project history and describe current status. Table 1 summarizes milestones in the project to date. These have been achieved within the original schedule and the initial capital equipment budget of $7.6 Million.

Injector

The cusp-type ion source provided by Culham has produced beam routinely since 10/80. It has operated at 60KV at .1% duty and 55KV at 10% duty (50mA peak current) protons. The source produces a very uniform beam with emittance of about 0.1π mm-mrad normalized. A present disadvantage is a 50% proton fraction. Recent developments on similar sources have improved this considerably, however.[7] Frequent extractor arc-downs at high powers are an operational problem which we are addressing. Beam transport in the terminal is now being optimized in conjunction with optics studies in the low energy beam transport. Figure 1 shows the terminal installation.

The accelerating column has been conditioned to 800KV and beam has been accelerated into LEBT at 780 KeV, the nominal injection energy of the Linac. The peak current in LEBT has been 20mA at 2.5% duty. The measured normalized emittance is 1π mm-mrad for 95% of the beam. The problems in the injector area are: protection of electronics from damage caused by arc-down transients; reducing the frequency of arc-downs; and speeding the restoration of operating settings after arc-downs.

Low Energy Beam Transport

LEBT consists of three quadrupole triplets (variable strength permanent magnet) with interspersed diagnostic boxes, double harmonic buncher copied from CERN, and four electromagnet quadrupole singlets for matching into the Linac. As shown in Figures 2 and 3, this system is complete except for the buncher. Beam transmission is 100% through the triplets, although emittance scans show that the optics do not yet correspond to the design. Computer simulation indicates that observed behavior is explained by the beam being over-focused in the accelerating column. This is due to the peak current being lower at the present time than called for in the design. Minor modifications to the terminal optics are being undertaken to solve this problem. The buncher is undergoing RF tests and will be installed after preliminary accelerator transmission studies are complete.

Accelerating Structure

The tank is mechanically complete.

TABLE I

Project Milestones

9/76	NEN decision to investigate (build or buy) linac.
6/77	First NEN person hired for linac project.
1/78	Preliminary budget and project approval.
6/78	Complete design team at NEN, schedule generated.
10/78	Machine specified, ground breaking, major orders placed.
10/79	Design complete - first major equipment delivered.
1/80	Building occupancy.
10/80	60 KeV beam.
4/81	780 KeV beam.
10/81	45 MeV beam.

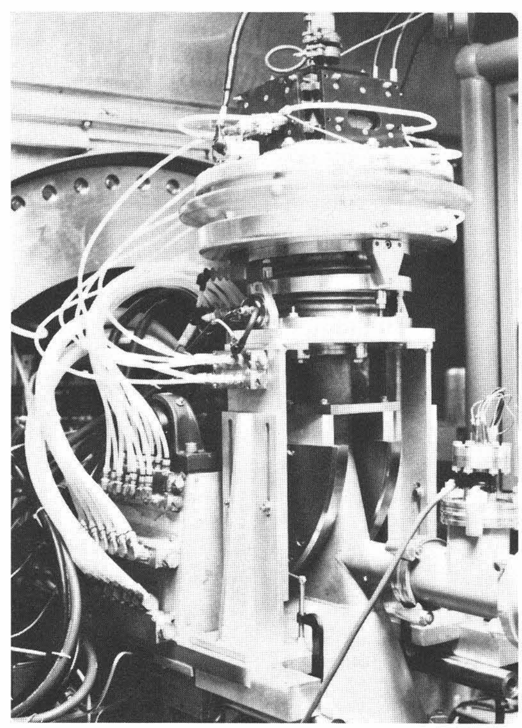

Fig. 1 Ion source and 90° bending magnet installed in high voltage terminal.

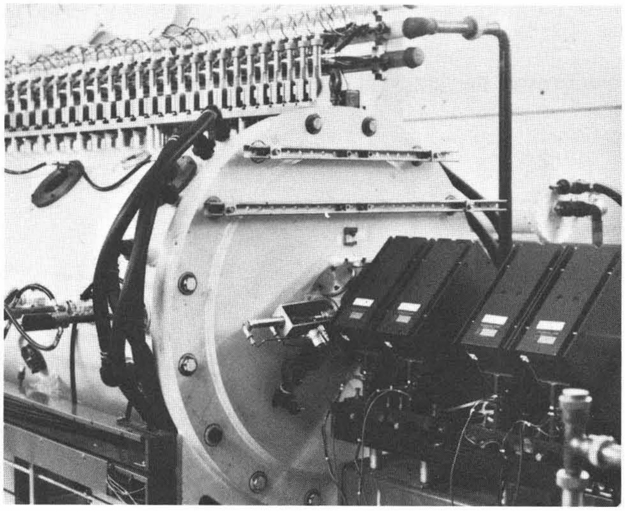

Fig. 2 Accelerating Tank and LEBT matching quadrupoles.

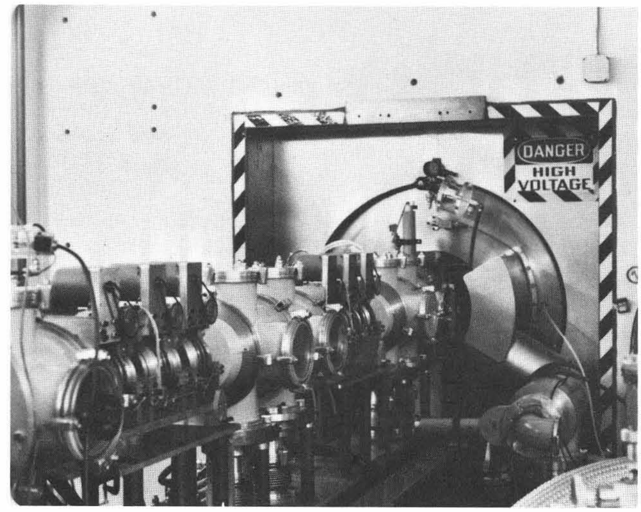

Fig. 3 Low energy beam transport and base of accelerating column.

The vacuum system has worked very well, requiring only three hours to pump down to acceptable pressure to apply RF power. The measured tank Q is over 70,000, about 70% of theoretical. R.F. power conditioning required only a few days to achieve required acceleration fields at 2.3MV per meter, 2.3MW peak power. This level results in maximum field gradients of 15 MV/m on the drift tubes, just about at the Kilpatrick criterion.

Figure 4 is a plot of E_z on axis as a function of distance down the tank, for a "flat" field, E_0 = constant. The field was "flattened" to better than ± 5% by shaping the tuning bar. The steps in the peak E_z at cell 28 and cell 71 are due to changes in tank diameter at these points and the associated change in gap to cell length ratios.

The tank has a very high "tilt sensitivity" of 1.4%/KHz due to the single cavity, 26 meters in length. Efforts to post coupler stabilize the tank have not yet been successful. Work will continue until we resolve this difficulty.

Initial 45 MeV beam tests were at peak beam currents of 15μA and 0.1% beam duty. No measurements were made of the emittance growth through the linac. No measurable residual activity was found except in the 40 MeV degrader and beam stop, so we conclude there are no gross problems with the machine dynamics or the permanent magnet drift tube magnets. Transmission measurements are scheduled for January 1982 and final accelerator tuning will begin in March 1982.

R.F. System

Three RF amplifier chains using RCA 7835 triodes as final power amplifiers are installed at NEN, along with the transmission line-combiner-splitter system. One amplifier chain is fully operational with a simplified switch for the modulator as an interim solution to a modulator instability problem. This system has performed at full 200 KW average power and 3MW peak power. Tests were completed on the final modulator system at the manufacturer's at full ratings of 200KW average and 5MW peak. The second RF chain is now being tested with this modulator installed at NEN. The final chain will be tested along with phase and amplitude control servos by Jan. 82. Experience so far indicates that the RF systems and the transmission line elements are very reliable at reduced average power levels. Experience at higher average powers is limited.

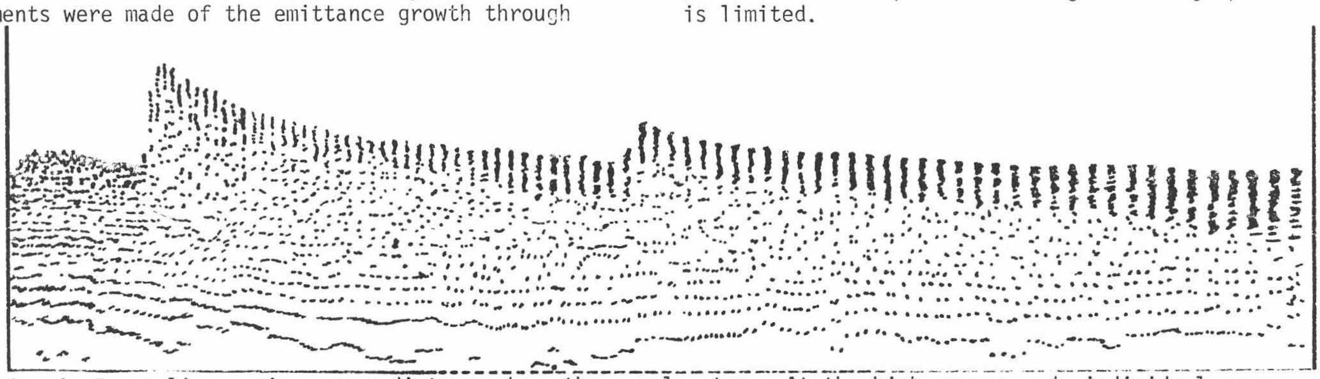

Fig. 4 E_z on linac axis versus distance down the accelerator. At the high energy end, individual gaps can be distinguished. The two discontinuities are required by the tank diameter changes at cells 27 and 70.

Control System

An aspect of the NEN linac not previously described is the control system. All injector, beam line, accelerator, and RF system equipment is controlled by a system of distributed 6800 microprocessors, fiber-optic communication links, and central VAX 11/780 computers. The communications network, some microprocessor I/O cards, and interface are of in-house design. This system has operated for over one year on various sub-systems. A central console with color graphics for engineering system displays, along with the usual complement of tuning aids, has been implemented. Mobile consoles for use in engineering and trouble-shooting sub-systems are available. Program controlled start-up of the ion source is operational, as well as the save/restore function for selected "tunes" or collections of set-points.

Work is underway to condition the accelerating column under program control. Our goal is to continue to develop all tuning procedures to the point where they can be implemented in software to remove the burden from operators. We feel that this effort in the control area, and the extensive use of permanent magnet quadrupoles, are areas where we are testing recent technical advances for the first time on a machine of this type. We hope to make a contribution to the field as a result of our efforts in these areas.

Conclusion

The project is on schedule and within original equipment budget. We have achieved initial full energy beam. The basic equipment is installed to achieve design current and provide very sophisticated control and monitoring. Much work remains to obtain reliable high current operation.

Acknowledgement

Virtually every accelerator laboratory in the U.S.A. and many in Europe have contributed to our equipment designs and operational success. We want to express our appreciation to the people and institutions for this support. We feel that our project is a compelling example of the value to industry of research in the national laboratories.

References

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and A.J.T. Holmes, to be published.

Discussion

We have four electromagnetic quads at the entrance and exit of the linac to give us some matching capability, at different current levels, etc. They may not be necessary, but having the capability is good insurance.