ACCELERATING STRUCTURE PARAMETERS OF THE NEW ENGLAND NUCLEAR CORP. PROTON LINAC

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Summary

The design parameters of the New England Nuclear (NEN) 45-MeV Linac are presented. Emphasis is given to the small drift tube geometry used in conjunction with permanent magnet drift tube quadrupoles. Single cell and multi-cell rf cavity computations, as well as multiparticle dynamics results are discussed.

Linac Geometry

Preliminary design plans for a proton linac at NEN called for conventional electromagnetic quadrupoles for radial focusing at the low energy (0.75 MeV - 5 MeV) section of the accelerator. These electromagnets were to be followed by permanent magnet quads at higher energies, where gradient requirements are lower. The accelerating structure dimensions were to be similar to other facilities (BNL, CERN, LASL).[1]

In September of 1978 it became apparent that a new permanent magnet design, being developed by K. Halbach[2] of LBL and R. Holsinger[3,4] of NEN would allow the construction of magnets of sufficient strength to provide focusing for the entire linac. Since the outer diameter of magnets of this type with ∿10 Kg pole tip field is 7 cm, drift tube sizes approaching this value could conceivably be used. It was decided to investigate a geometry with a drift tube diameter of one half the conventional dimension of 18 cm. Several advantages are inherent in a design employing small permanent magnet quads. Primarily, they allow a geometry which has a shunt impedance higher than standard geometries, thereby offering the possibility of reduced power requirements. Secondly, engineering problems associated with drift tube quad power and cooling are eliminated. Also, drift tube length manufacturing tolerances are eased, since a deviation from design length has less effect on frequency than larger drift tubes.

The first step in geometry evaluation was to estimate the tank diameter required for 9 cm drift tubes and reasonable values of gap length to cell length ratios (g/L). This was done using data by Wilkins.[5] Single-cell geometries were then computer modeled using the program SUPERFISH,[6] which calculates resonant frequencies, fields, stem effects, power requirements and dynamics coefficients (T, S, etc.) for the unit cell. Gap lengths were adjusted to achieve resonance at the design value of 201.25 MHz. Given the average axial field (E_o), the synchronous phase (ϕ_s), and the dynamics coefficients from SUPERFISH, subroutine GENLIN of the program PARMILA[7] interpolates parameters of each cell in the linac and calculates exact cell dimensions, power requirements and the total number of cells. Several different geometries were evaluated in this manner.

For the linac section from injection (780 keV) to 5 MeV, a 110 cm diameter cavity was found to offer high shunt impedance, reasonably high values of the transit time factor and low drift tube surface fields. A geometry change at 5 MeV was dictated by a decreasing transit time factor (T), due to the increasing g/L values required to maintain resonance. For a design of this type which utilizes small drift tubes and larger tank diameters, g/L values have to increase more rapidly than in more familiar geometries.

At 5 MeV a cavity diameter change to 106 cm allowed g/L to be reduced to 0.216 which increased T to 0.85. This diameter is used to 22 MeV, where again low T values require a change in geometry to maintain structure efficiency.

The overall design (Fig. 1) achieves an estimated 15 - 20% savings in rf power in addition to the power savings from the use of permanent magnets.

Transition Regions

Unlike most previous linacs, where cavities of different diameter are separate, the NEN linac will have one tank of three different diameters (110, 106, and 102 cm). The changes in diameter are made rather abruptly at "transition regions" which were extensively modeled with SUPERFISH (Fig. 2). These multi-cell computations showed that the effect on the axial electric field was very small. Specifically, the diameter change at cell 28 perturbed cell 26 and cell 30 less than 1%. Average axial E-fields at cell 27 (increased) and cell 29 (decreased) were changed by ∿2.5%. When these perturbations were modeled with the dynamics program and compared with flat E-field dynamics data, no significant differences in longitudinal phase space plots were observed.

Dynamics Parameters

General Design Principles

Because the linac will be used to accelerate high average currents, basic dynamics considerations have centered around minimizing the possiblity of beam loss in the structure. A small average beam size and large transverse acceptance dictated high quadrupole gradients in a +-+- (N=1) configuration.

Also, we have attempted to match the beam longitudinally as well as transversely to minimize the emittance and beam size growth through coupling effects due to space charge forces.

Quadrupole Groups

As mentioned previously, transverse focusing will be provided by Samarium-Cobalt permanent magnets. The first of three magnet groups has the highest gradient readily achievable consistent with the drift tube geometry. Bore-size increases at 5 and 22 MeV decrease the radial space available for magnet material and therefore significantly decrease the quad gradient. To reduce the seriousness of mis-matches between sections, magnet lengths are increased (in half-inch increments) at these points. In this manner the quad focusing "strength" (effective length x gradient) is kept more nearly constant. The operating points on the familiar stability diagram[8] (zero space charge) are shown in Fig. 3. Single particle radial and longitudinal oscillations (Fig. 4) as well as multiparticle, zero space charge, horizontal and vertical profiles (Fig. 5) were used in selecting the final quadrupole group parameters.

The central position on the stability diagram of the group I magnets suggests a high value for the transverse acceptance. PARMILA computations indicate a value of approximately 50π cm-mr for the transverse phase space (space charge forces neglected) area.

Matching

Chasman[9] and Batchelor[10] have investigated the parameters associated with matching in 6-D phase space assuming a uniformly charged ellipsoid. Using the formulation presented in that work, a computer program[11] was written to find the matched beam input parameters (average beam size and energy spread), given an initial phase spread and transverse emittance. This data was then used to estimate transverse and longitudinal beam parameters (alpha, beta, ΔW) when a more realistic beam (non-uniform charge distribution) was input into PARMILA. Emittances and beam profiles were then plotted (Fig. 6). Once we had determined the matched beam parameters in this manner with this somewhat idealized beam (ellipsoidal in longitudinal as well as radial phase space), the next step was to attempt to approximate the $\Delta\phi$-ΔW phase space ellipse with the buncher (CERN design harmonic type). Because the effective voltage required for a well matched beam is known, the dynamics program was used to find the buncher-linac distance which effectively populated a specified phase spread of 27°. With buncher voltages of 27 KV and 10.8 KV on the 200 MHz and 400 MHz bunchers, respectively, this distance was found to be 125 cm. Figures 7 and 8 show 50 mA beam profiles with a bunched beam input. Capture efficiency is calculated to be ~85%. Those particles outside the longitudinal acceptance are lost before 5 MeV and therefore should not be a significant source of induced radioactivity.

The low energy beam transport (LEBT) focusing will be provided by three quad triplets before the buncher and four quad singlets after the buncher. Program TRACE[12] has been used extensively in modeling LEBT, especially that section after the buncher which is used for transverse matching into the linac. Figure 9 shows an example of TRACE output in this beam line section.

Conclusion

Extensive computer analysis of the accelerator is nearly complete. Simulation of particle dynamics and computer modeling of the accelerating structure indicate that the small drift tube geometry and high gradient permanent magnet focusing will give NEN a linac capable of efficiently accelerating high average beam currents.

Acknowledgements

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Parameter	Unit	Cavity Section: 1	2	3
Cavity Length	M	2.85	10.20	14.60
Cavity Diameter	M	1.10	1.06	1.02
Input Energy	MeV	0.78	4.97	21.95
Output Energy	MeV	4.97	21.95	45.34
No. of Cells		27	43	38
Cavity RF Power (Approx.)	MW	0.25	0.79	1.16
Synchronous Phase	Deg.	-30	-26	-26
Axial Transit Time Factor (T)		0.652-.745	0.850-.750	0.834-.721
Average Axial Field (E_o)	MV/M	2.30	2.30	2.30
Peak Surface Field	MV/M	11.0-9.1	13.6-12.1	14.5-14.4
Average Shunt Impedance (Z)	MV/M	78.0	88.6	86.9
Drift Tube Diameter (d)	cm	9.0	9.0	9.0
Bore Hole Diameter (HD)	cm	2.0	2.50	3.0
Upper Profile Radius (r)	cm	2.0	2.0	2.0
Lower Profile Radius (r_{hc})	cm	0.5	0.5	0.5
Stem Diameter	cm	2.86	3.18	3.18
Gap/Cell Length (g/L)		0.242-.352	0.216-.365	0.283-.376
Quadrupole Length	cm	3.81	5.08	7.62
Quadrupole Gradient	Kg/cm	8.80	6.00	3.80

Fig. 1 Geometry and Dynamics Parameters

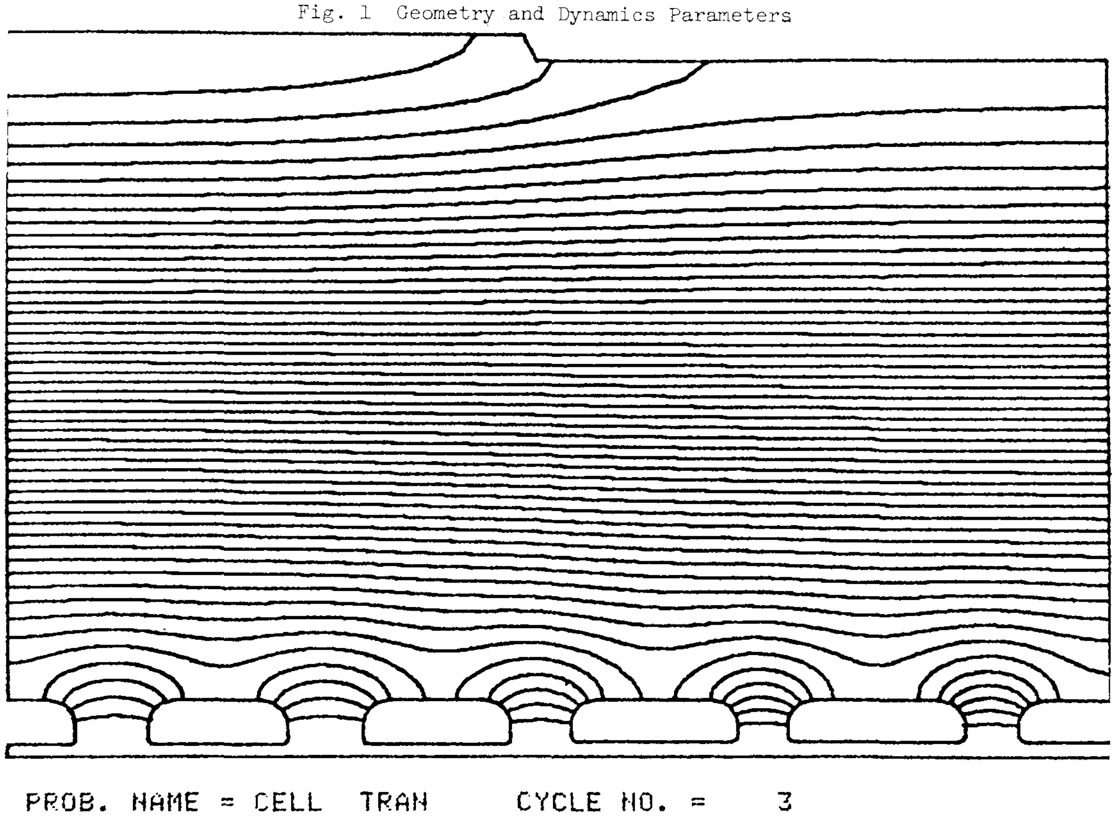

Fig. 2 Transition Region SUPERFISH Output

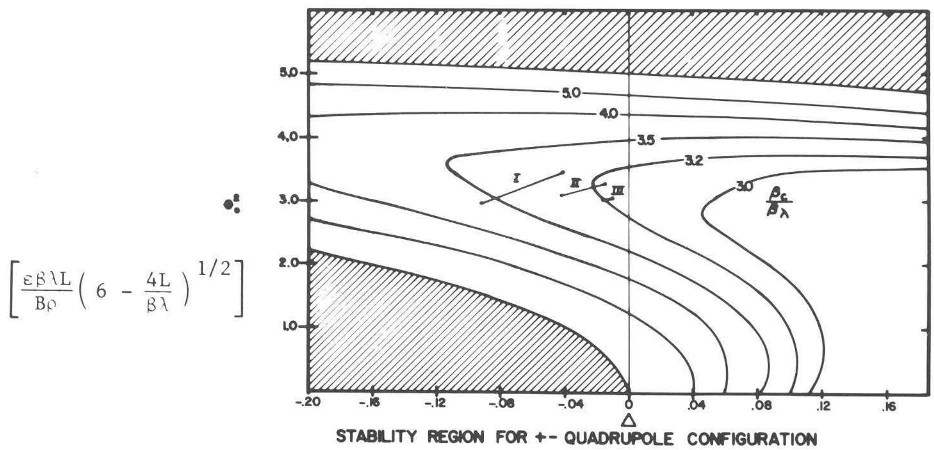

Fig. 3

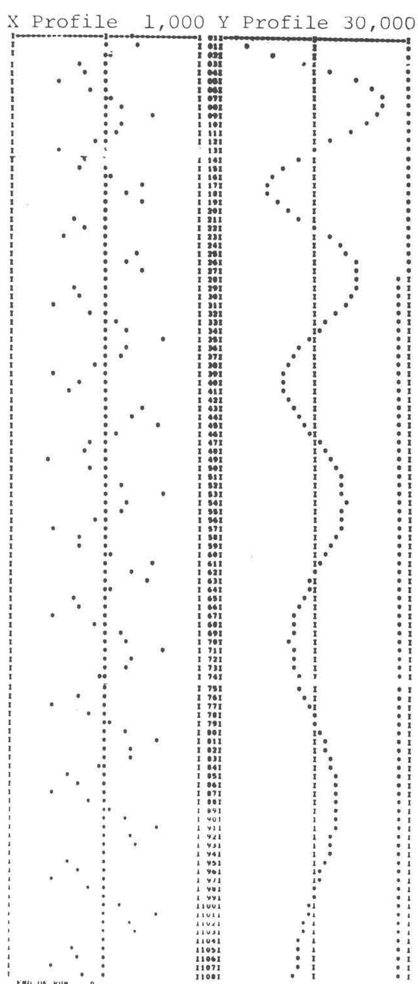

Fig. 4

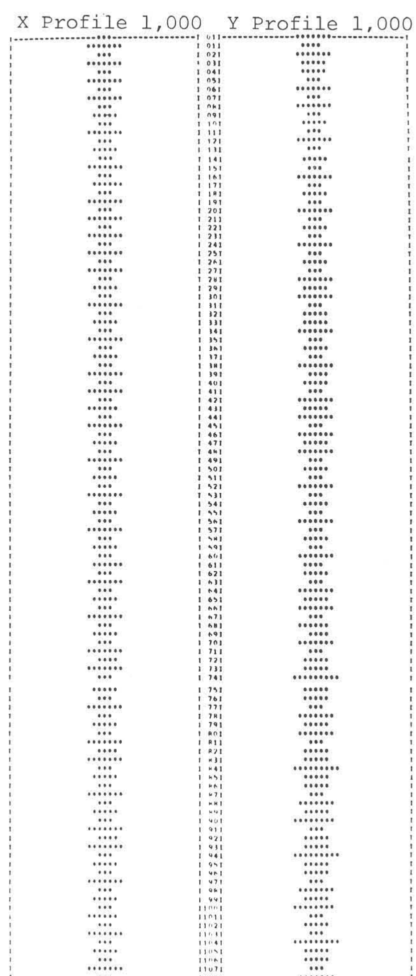

Fig. 5

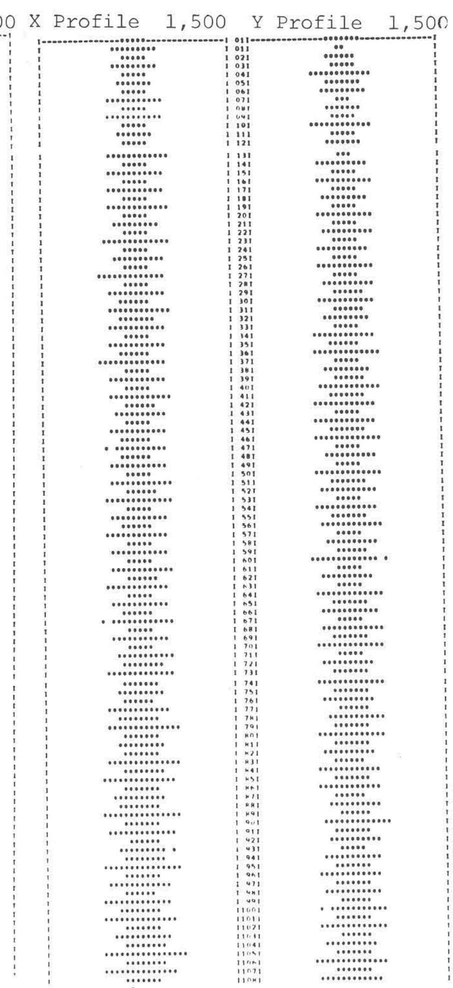

Fig. 6

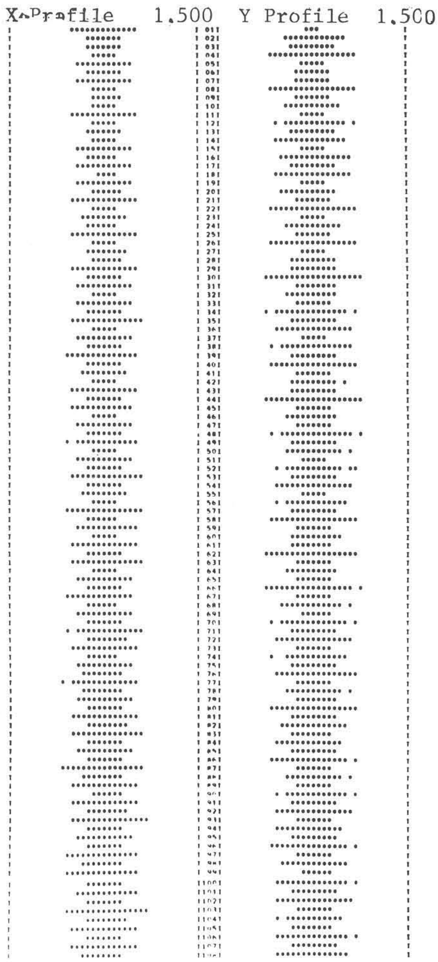

Fig. 7

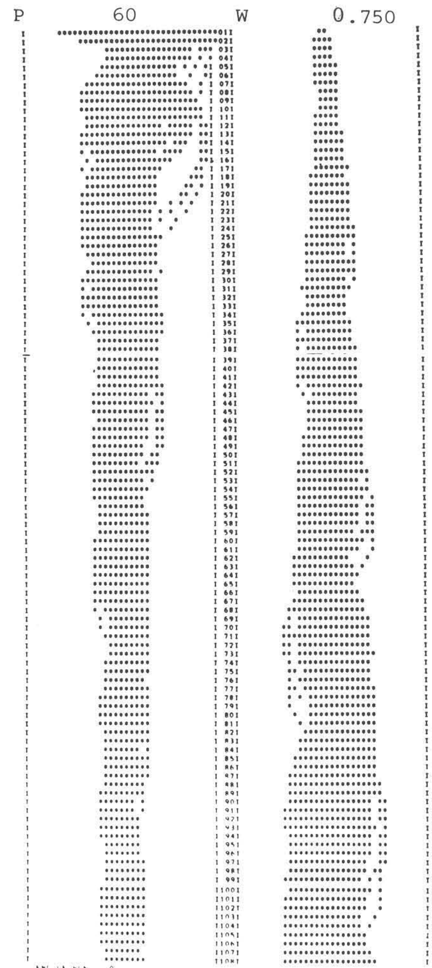

Fig. 8

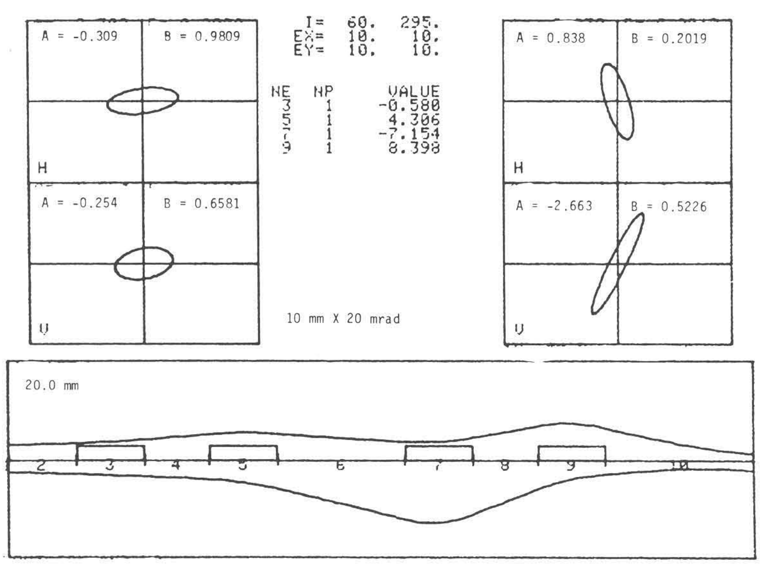

Fig. 9