An 80 MeV Injector Linac for BSF Future Project

S. Inagaki, H. Baba, M. Miki and H. Sasaki
National Laboratory for High Energy Physics

1. Introduction

A rapid cycle proton synchrotron with a maximum kinetic energy 800 MeV, maximum intensity 6 x 10^{13} ppp and repetition rate 50 Hz is under consideration as a BSF future project$^{1)}$. The injector will be 80 ∿ 100 MeV H^- linac with pulse width 350 μs and intensity 30 mA.

The success$^{2)}$ of RFQ in LANL suggests the alternative to a huge Cockcroft-Walton preinjector. Even though the attainable maximum energy through RFQ requires a deliberate study, 1 MeV will certainly be obtainable, which enables the use of klystron around 400 MHz as RF power source. Therefore the accelerating structure of this injector is devided into three stages: 50 ∿ 100 keV H^- ion source, 1 MeV RFQ or APF and 80 MeV Alvarez linac. This paper describes the design study, mainly of Alvarez structure part.

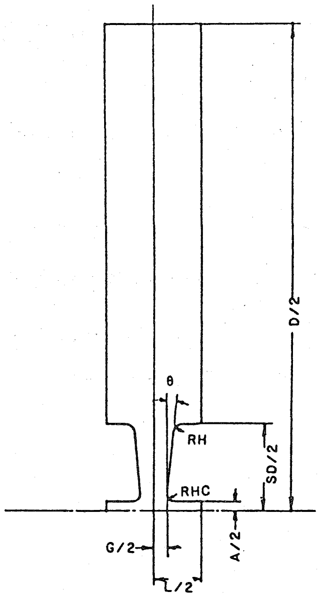


Fig. 1

2. Computation of Parameters by the Aid of SUPERFISH

If an Alvarez linac is excited at 400 MHz, the diameter of the cavity reduces nearly to the half of the present proton linac$^{3)}$ at KEK and the average accelerating field can be made higher, say 3.5 MV/m. For a flat faced drift tube with fixed bore diameter and corner radius (A = 1.0 cm, RHC = 0.5 cm and RH = 1 cm, Fig. 1),

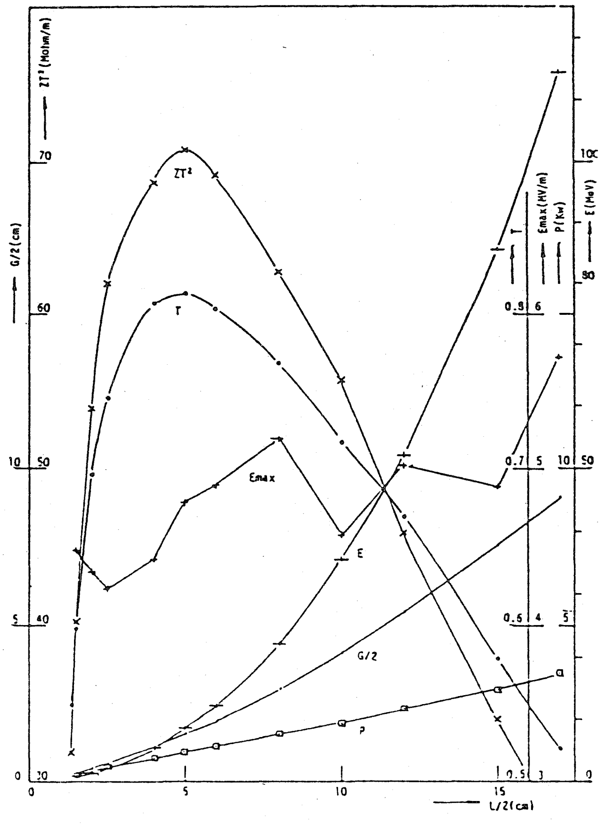


Fig. 2

an optimization was made at relatively low energy to obtain drift tube outer diameter SD = 9.0 cm and cavity diameter D = 48 cm. Next for these fixed dimensions, the half gap length (L/2) was computed that will give the resonant frequency of 400 MHz at different representative cell length. The values of transit time factor (T), effective shunt impedance (ZT^2), power loss (P), etc. were tabulated as the function of L/2 and used for interpolation (Fig. 2).

3. Cell Dimension and Longitudinal Oscillation

The geometrical and RF parameters for a constant synchronous phase (ϕ_S = -30°) are computed for several average accelerating field. The cell number, total length and RF power loss at $\overline{E}_0$ = 3.0 MV/m, 3.5 MV/m and 4.0 MV/m are shown in Table I. Table II shows the energy, cavity length, number of cells contained in a cavity and RF power for 5 partitions at $\overline{E}_0$ = 3.5 MV/m. From the view point of cavity numbers, cell numbers, RF power and sparking limit (the surface electric field is less than one third of Kilpatrick criterion), $\overline{E}_0$ = 3.5 MV/m is chosen for the first candidate.

$\overline{E}_0$ (MV/m)	Cell Number	Total length (m)	RF Power Loss (MW)
3.0	252	43.86	3.76
3.5	216	37.59	4.39
4.0	189	32.89	5.01

Table I

80 MeV Alvarez Linac (5 Cavities)

Cavity Number	Energy (MeV)	Length (m)	Number of Cells	Power (MW)		
				Cavity	Beam	Total
1	18.8602	7.4444	82	0.869	0.566	1.434
2	35.9399	7.5470	43	0.884	0.512	1.396
3	51.6727	7.5034	34	0.899	0.472	1.371
4	66.1500	7.3513	29	0.910	0.434	1.344
5	80.1218	7.5505	27	0.939	0.419	1.358

Table II

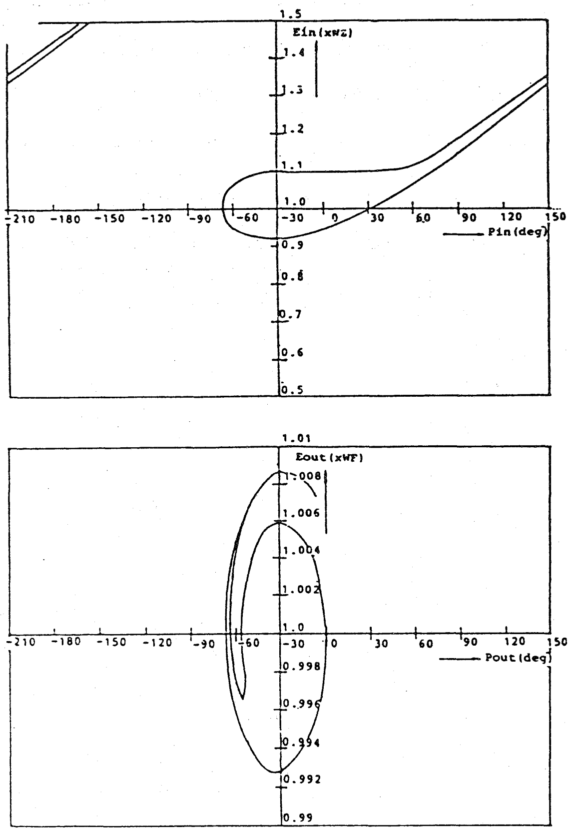


Fig. 3(a)(top) and (b)(bottom)

Figure 3(a) is the acceptance in ϕ-E space, in which WZ is the synchronous injection energy (1 MeV). As is well known a beam with several percent higher energy than WZ can be better captured. Figure 3(b) is the emittance, showing that the energy spread of the beam at the exit extends from -0.7 % to +0.6 % of the synchronous energy WF (80.1 MeV) and is bunched within ±30°. As this acceptance corresponds to the beam of Fig. 3(a), the actual one can be expected to be much smaller. Figure 4 shows the phase oscillation from 1 MeV to 3 MeV and particle distribution in the phase-energy space at the exit (upper right).

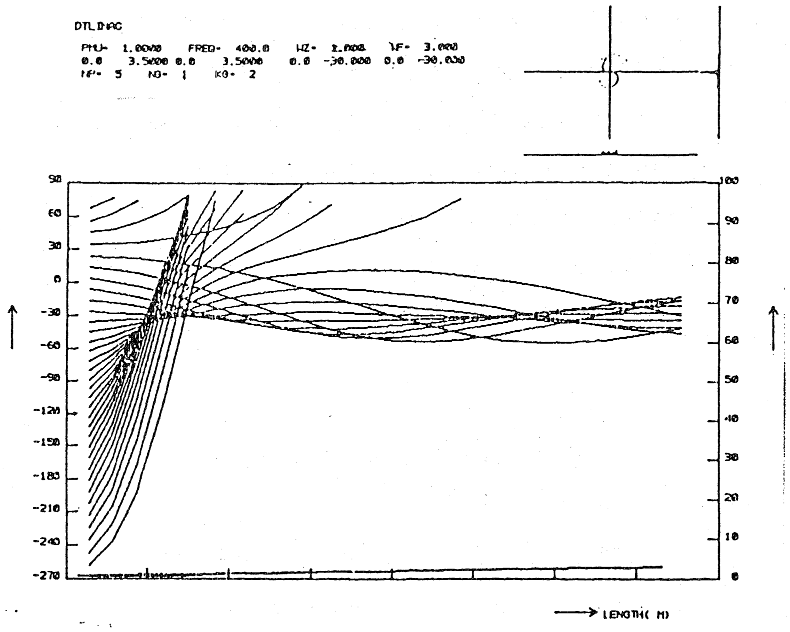


Fig. 4

4. Focussing System

As is the case of KEK 20 MeV linac[4)], the field gradient G(N) of the N-th quadrupole magnet is so designed as to make Λ (= $|K(S)|\cdot L_{eff}/L$) constant. Therefore,

$$G(N) = (-1)^{N+1}G(0)\frac{\beta_{in}}{\beta(N)}\cdot\frac{\gamma(N)}{\gamma_{in}}\left(\frac{L}{L_{eff}}\right)_N\cdot\frac{1}{2}$$

in FDFD scheme, where L and L_{eff} means the cell length and effective quadrupole magnet length, respectively. β and γ are relativistic factors. The defocussing effects due to RF and space-charge are taken into consideration as impulse effects at the center of drift space. Figure 5 shows the normalized acceptance for the cell structure described in Section 3. The abscissa designates the value of field gradient of the first quadrupole

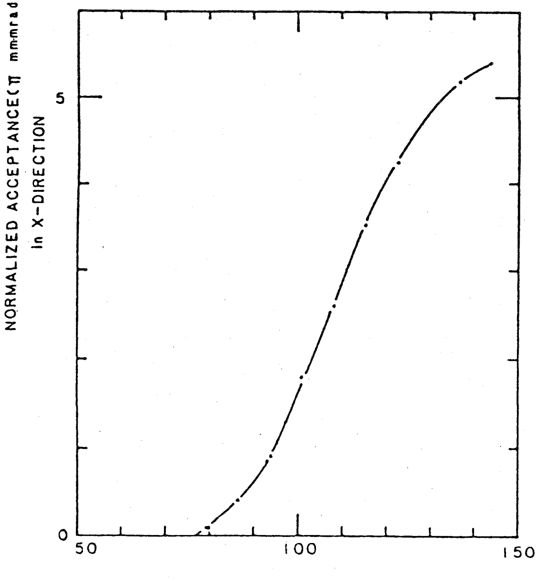


Fig. 5

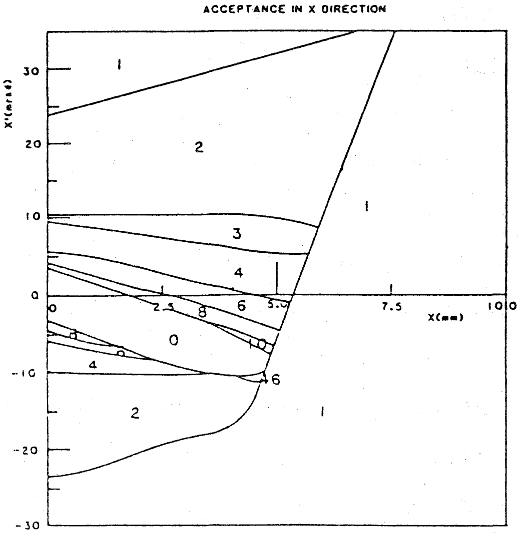


Fig. 6

magnet. Due to a relatively high accelerating field $\overline{E}_0 = 3.5$ MV/m, the defocussing force becomes so large that focussing field gradient G(1) is critical above 100 Wb/m^3. This will be overcome by using rare earth-cobalt permanent magnet$^{5)}$. The acceptance at G(1) = 130 Wb/m^3 is shown in Fig. 6, where the number indicates the cell where the beam is lost and the beam with number "0" is accepted throughout the structure.

5. Discussion

If the face of a drift tube is tapered ($\theta \neq 0$ in Fig. 1), the transit time factor and effective shunt impedance increases remarkably (Fig. 7). The electric field on the surface is shown in Fig. 8. These results suggest to use tapered drift tubes with 15° for 15 ∿ 50 MeV, 30° for 50 ∿ 80 MeV and 45° for 80 ∿ 100 MeV as an illustration.

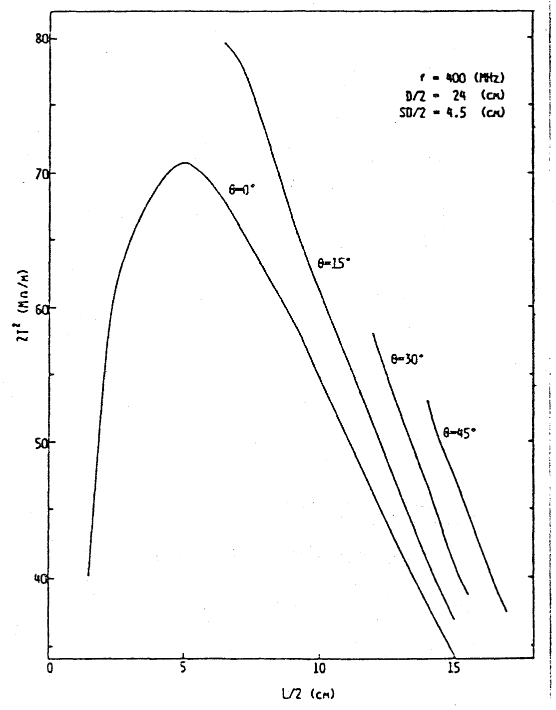


Fig. 7

The build up time of the cavity for Q = 6.5 x 10^4 is about 275 μs. If one adds 100 μs as a margin to the minimum beam duration 350 μs, the duty factor becomes 3.6 %. 400 MHz klystron with duty factor 5 % and peak power 2.5 MW is expected to be developed without much difficulty. Figure 9 shows the block diagram of the first scheme described in Section 3. Using tapered faced drift tubes, however, 100 MeV may be obtained by the same number of klystrons.

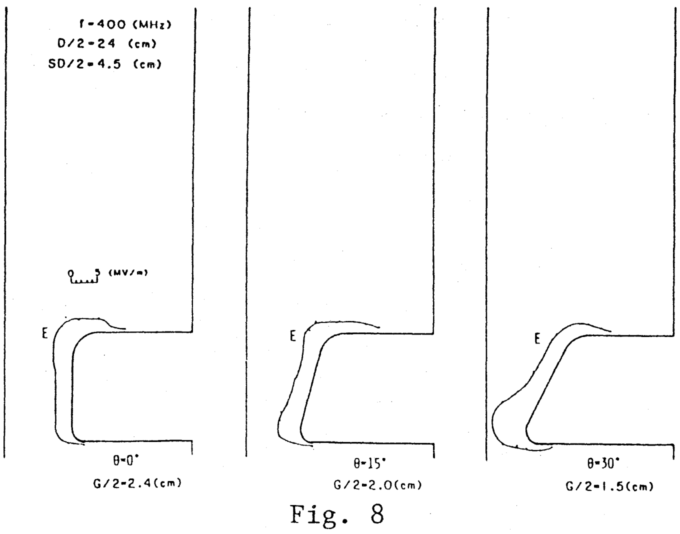
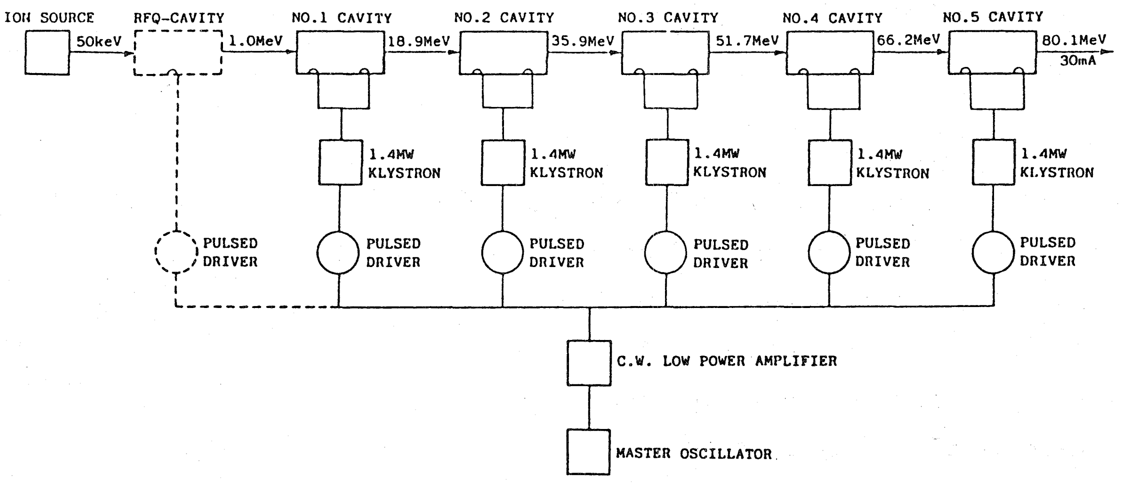


Fig. 8

The experimental studies of post couplers and permanent magnets are essential to realize the present proposals. The investigations of low energy structure, RFQ or APF, and H^- ion sources need to be started later on. The intensity modulation of the beam with the frequency of synchrotron at an early stage is proposed to avoid the radioactive contamination of the synchrotron.



OUTLINE OF 80MeV INJECTOR LINAC

Fig. 9

Acknowledgement

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