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Design of 433.3 MHz Alvarez Drift Tube Linac and Beam Matching Section

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A 433.3 MHz drift tube linac (DTL), which accelerates proton out of the 2 MeV RFQ linac to 7 MeV, is designed. The drift tube is 5.5 cm diameter and contains a permanent magnet quadrupole lens. A beam matching section, which consists of quadrupole magnets and a two-gap buncher, is also designed for the transverse and longitudinal beam matching between the RFQ linac and the DTL.

KEY WORDS: Alvarez Linac/ Drift Tube Linac/ Permanent Quadrupole Magnet/ Beam Matching Section/

1. INTRODUCTION

A 7-MeV proton linac is now under construction at the Nuclear Science Research Facility, Institute for Chemical Research, Kyoto University. The first stage of this linac is a 2-MeV radio-frequency quadrupole (RFQ) linac[1,2] and the second stage is an Avarez drift tube linac (DTL).

The drift tube size is so far not small because it contains usual electro-magnet. The development of the strong permanent magnet quadrupole makes it possible to fabricate small drift tubes and this allowed a high frequency operation. The frequency of our system is 433.3 MHz and is about twice higher than that of recent proton linacs. A buncher and focusing magnets will be installed between the RFQ linac and the DTL for the beam matching.

2. PARAMETERS OF DTL

The effective shunt impedance was calculated by SUPERFISH for various sizes of drift tube diameter and tank diameter. The other parameters such as bore radius, nose radius, corner radius and nose angle were kept constant in these calculations. Table 1 shows the effective shunt impedance at both the entrance and the exit of DTL. Power loss on the stem surface was not included in these calculations. Though the effective shunt impedance of 5 cm diameter drift tube is the highest in these calculations, 5 cm diameter drift tube is too small to contain the magnet of enough focusing strength. Thus the drift tube diameter of 5.5 cm and the tank diameter of 45 cm were adopted.

The stem diameter of 12 mm is required for the mechanical reason. According

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Table 1. The effective shunt impedance.

Drift Tube Diameter (cm)	Tank Diameter (cm)	Effective Shunt Impedance MΩ/m	
		2 MeV	7 MeV
5	44	88.1	105.3
	46	90.6	105.8
	48	87.8	97.6
5.5	44	84.6	99.9
	45	85.5	101.5
	46	86.2	99.2
	47	85.0	96.4
6	42	75.3	91.1
	43	77.2	93.3
	44	79.4	94.7

Table 2. Main parameters of the DTL.

Input Energy	2.01 MeV
Output Energy	7 MeV
Tank Diameter	450.94 mm
Length	1867.52 mm
Drift Tube Diameter	55 mm
Bore Radius	5 mm
Length	38.8 mm ∼ 65.3 mm
Number of Cell	29
Stem Diameter	12 mm
Average Accelerating Field	3.58 MV/m
Magnetic field gradient	17.5 kG/cm
Magnet Length	28.8 mm
Bore Radius	5.5 mm

to SUPERFISH results the frequency shift due to 12 mm diameter stem is 0.35 MHz and that due to the increase of tank radius is −1.39 MHz/mm. The tank diameter was increased by 0.252 mm in order to compensate it. Five block tuners of 10 cm diameter are installed on the wall to adjust the resonant frequency. Considering the adjustable range the tank diameter of 45.094 cm was chosen.

The average accelerating field is 3.58 MV/m. The maximum surface field is 26 MV/m, which is 1.3 times of the Kilpatrick limit. The tank contained 28 drift tubes and two half drift tubes. The parameters of DTL are shown in Table 2.

3. QUADRUPOLE MAGNET

The calculated normalized transverse emittance of the beam from the RFQ linac is 2.06 π mm mrad according to the PARMTEQ simulation. As the beam radius was designed to be less than a half of bore radius in DTL, the normalized transverse ac-

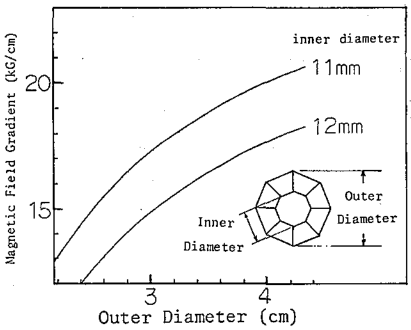

Fig. 1. Magnetic field gradient of 8-segment permanent quadrupole as a function of outer diameters at the inner diameter of 11 mm and 12 mm.

ceptance of the DTL was required to be more than 8.24 π mm mrad. The shortest drift tube length of 3.88 cm limits the quadrupole magnet length to be 2.88 cm. The magnetic field gradient of more than 16.7 kG/cm is needed in this case. Figure 1 shows the magnetic field gradient as a function of outer diameter of 8-segment quadrupole magnets.[3] The magnet material is supposed to be HS30CH of HICOREX-SUPER(Nd-Fe-B) (HITACHI METALS, Ltd.). The inner diameter of the magnet of 1.1 cm required the minimum outer diameter of 2.80 cm to produce the sufficient field strength. The quadrupole magnet of 3.07 cm diameter could be installed in the 5.5 cm diameter drift tube, and the magnetic field gradient of 17.5 kG/cm is expected.

4. LONGITUDINAL MATCHING

The PARMTEQ simulation indicates the phase spread of the output beam of the RFQ linac is ± 28 degree. Because the RFQ linac and the DTL have the end plates, the drift space cannot be eliminated between the vane end of the RFQ linac and the first cell of the DTL. Figure 2 shows the phase spread as a function of drift distance

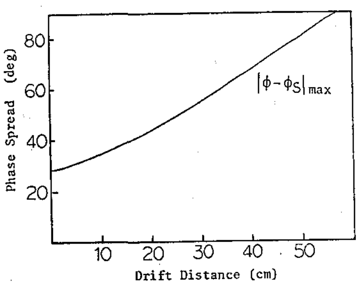

Fig. 2. Phase spread as a function of the drift distance from the vane end.

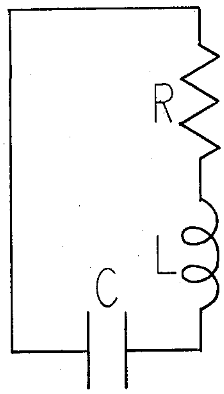

Fig. 3. A half part of the equivalent circuit of the two-gap buncher.

from the vane end of the RFQ linac. The synchronous phase of DTL was chosen to be −30 degree and the phase spread should be within ±30 degree. A buncher is needed between the RFQ linac and the DTL in order to compress the phase spread. A coaxial two gap cavity was adopted to reduce the diameter of the buncher. Parameters of this buncher were determined as follows.

1) Because this buncher is π mode, the length from the entrance to the exit is $\beta_s\lambda$, where $\beta_s c$ is the velocity of the synchronous particle and λ is the wave length.

2) A half part of the equivalent circuit of this buncher is shown in Fig. 3. The shunt impedance Z of this circuit is

$$Z=2\omega^2\frac{L^2}{R},$$

where $\omega^2=1/LC$, ω is the angular frequency, L and R are the inductance and resistance of the stem respectively, and C is the capacitance between drift tubes.

3) If the amplitude of the field is constant along the gap, transit time factor is $\sin\Delta\theta/\Delta\theta$, where $\Delta\theta$ is the phase change while the particle passes through a half of the gap. Parameters were searched to maximize the effective shunt impedance $(\sin\Delta\theta/\Delta\theta)^2\cdot Z$.

For the 4 cm diameter of drift tube of the buncher and the 1 cm diameter of the stem, the length of the stem and gap are 15.2 cm and 1.24 cm respectively and the shunt impedance of the cavity is expected to be 15 MΩ.

Long drift distance to the buncher makes the phase spread wide and bunching voltage became out of linear range around the phase of $-\pi/2$. The acceptable phase spread of ±55 degree permits the 30 cm drift distance to the buncher.

Figure 4 shows the position of minimum phase spread as a function of bunching voltage, and also shows the phase and energy spread at that position. The acceptable energy spread for the longitudinal stability of the DTL can be calculated by the following equation neglecting space charge effect.[4)]

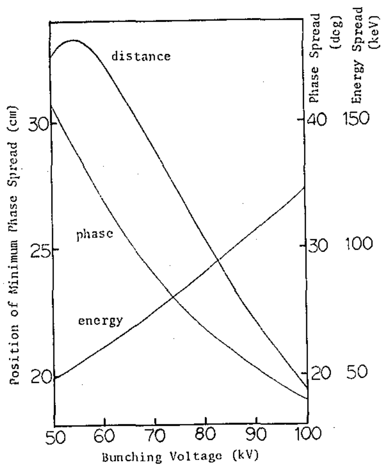

Fig. 4. The position of manimum phase spread after the buncher as a function of the bunching voltage. The phase and energy spread at that position are shown.

$$\Delta W=\left\{\frac{2eE_0\lambda\beta_s{}^3\gamma_s{}^3m_0c^2}{\pi}(\phi_s\cos\phi_s-\sin\phi_s)\right\}^{1/2},$$

$$\gamma_s=(1-\beta_s{}^2)^{-1/2},$$

where e is the charge of electron, E_0 is the average accelerating field, λ is the wave length, $\beta_s c$ is the velocity of the synchronous particle, m_0c^2 is the rest mass energy of the particle and ϕ_s is the synchronous phase of the DTL. Using above equation the acceptable energy spread for the longitudinal stability is 140 keV. Therefore 23 cm drift distance after the buncher is required so as to fit the longitudinal phase space of the beam to the longitudinal acceptance.

5. TRANSVERSE MATCHING

It is important to match the ellipses of transverse phase space to those of acceptance of the DTL for the reduction of the beam loss and the stable acceleration. Eight permanent magnets are installed in the beam matching section between the RFQ linac and the DTL. It is desirable to use the same quadrupole magnets as those in the drift tubes of the DTL for cost performance. The ellipse parameters (α, β and γ) of the phase space were optimized to those of the acceptance of the DTL by changing the magnet positions. A computer code "ASOBT" (Automatic Search of the Optimum Beam Transport) was developed to perform the optimization of the transverse matching section automatically. The transfer matrixes were optimized by the Simplex method.[5]

Figure 5 shows the DTL acceptance and Fig. 6 shows the phase spaces of transported beam. Figure 7 shows the beam profiles in the beam matching section.

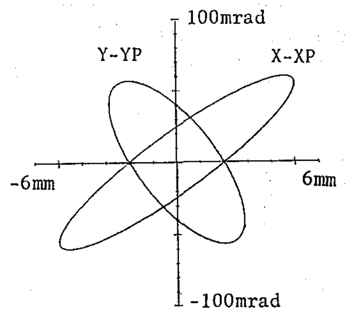

Fig. 5. The transverse acceptance of the DTL.

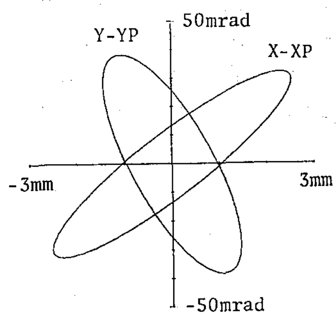

Fig. 6. The phase spaces of transported beam.

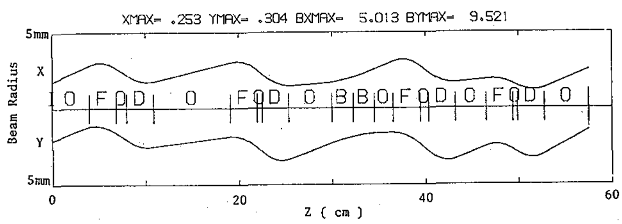

Fig. 7. The beam profiles in the beam matching section. The symbols of O and B represent drift space and bunching element. The symbols of F and D represent focusing and defocusing element in the X-direction.

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