DESIGN OF THE INJECTION SYSTEM OF POSITRON GENERATOR

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ABSTRACT

The beam trajectories are calculated for the prebuncher and buncher to be used for the positron generator which is to accelerate high intensity electrons of 10 A with a duration of 1.5 ns. Dimension of the cavities of these prebuncher and buncher is determined for manufacturing. Beam transport system is also designed, which consists of solenoid coils for the beginning and quadrupoles for the rest of the injector.

INTRODUCTION

Main components of the injection system are an electron gun, a prebuncher, a buncher and two accelerator guides, and the design of these prebuncher and buncher were made together with a transport system. These components are similar to those used in the PF linac injector[1], however, the injection voltage is to be raised to 150 kV to make easier to draw higher current from the gun, whereas it is 100 kV for the PF linac. Attention was paid to the beam trace to reduce space charge effect since acceleration of high current is essentially important in this design.

To focus the electron beams, magnetic lenses and solenoid coils are used in the beginning where the electrons have low energy, and then quadrupoles for the rest.

DESIGN OF PREBUNCHER AND BUNCHER

Positrons produced in this generator are accelerated with the PF linac, TRISTAN accumulation ring and main ring to be used in high energy physics research on e^+-e^- collision experiment. To obtain a good statistics in the measurements the positron beam intensity must be high enough, and it should be at least more than a few mA in the linac. The conversion efficiency of an electron to positrons is as low as a fraction of a percent around an energy of 200 MeV, which is the planned electron energy at the converter to positrons. So the target electron current aimed at is determined to be 10 A, and higher the current the more desirable.

The conversion efficiency is naturally expected to be proportional to the electron beam power in a narrow energy region, so that the electron energy should be as high as possible in the limited region. So the output of klystron is divided into two, and one of then is again divided into two, one for the buncher and prebuncher the other for the first accelerator guide with a length of 2 m. The other output of the first power divider is fed to the second accelerator guide with a length of 4 m. This arrangement is more advantageous to gain higher energies than that adapted in the PF[1,2].

As for the spread of beam phase at the output, or the bunch width, it is better for the spread to be small, but not necessarily to be very small, because in focussing positrons diverging from the converter some broadening of the spread is expected.

Let us consider an electron of charge e, rest mass m_o, travelling in Z or the axial direction of the buncher. Denoting Z/free space rf wavelength λ_o by ξ, the total energy mc^2/rest energy m_oc^2 by γ, and the phase of electron relative to that of rf by Δ, the equation of motion for the electron is given by

$$\frac{d\gamma_i}{d\xi_i} = -\alpha \sin\Delta_i + \alpha_{sc} \qquad (1)$$

Table 1. α and β values

PREBUNCHER			BUNCHER		
CAV. No.	α	β	CAV.No.	α	β
1	0.036	0.70	1	1.37	0.78
2	0.038	"	2	1.43	0.80
3	0.040	"	3	1.50	0.83
4	0.042	"	4	1.58	0.87
5	0.044	"	5	1.66	0.91
6	0.046	"	6	1.72	0.945
7	0.048	"	7	1.77	0.965
			8	1.82	0.983
			9	1.86	1.00
			10	1.90	"
			.	"	"
			.	"	"
			.	"	"
			44	1.90	1.00

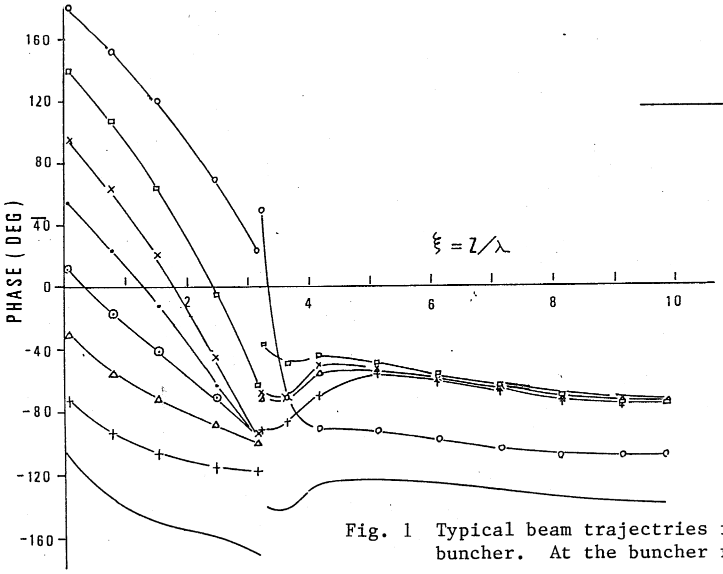

Fig. 1 Typical beam trajectries in the prebuncher and buncher. At the buncher rf is shifted by 30°.

$$\frac{d\Delta_i}{d\xi_i} = 2\pi\left(\frac{1}{\beta_\omega} - \frac{\gamma_i}{\sqrt{\gamma_i^2-1}}\right) \tag{2}$$

where $\alpha = eE\lambda_o/m_o c^2$, $\beta_\omega = \nu_p/c$, E is the maximum amplitude of electric field, and ν_p is the rf phase velocity. α_{sc} represents the force due to the space charge effect, and in its calculation the disk model is employed. According this model α_{sc} is given by[3]

$$\alpha_{sc} = \frac{2e\gamma^2 In}{m_o c^2 b^2 \pi}\,\frac{1}{N}\sum_{0}^{N}\sum_{n}^{\infty}\frac{J_1\frac{\beta_{on}b}{a}}{\beta_{on}J_1(\beta_{on})}\,\frac{e^{-\frac{|\beta_{on}\beta_\omega\lambda(\Delta_i-\Delta_j)|}{2a}}}{\gamma_j^2} \tag{3}$$

where N is the number of disks, I is the equvalent DC current, a and b are the pipe and beam radii, respectively, and β_{on} are successive zeroes of the zero order Bessel function of first kind (J_1). The suffix i represents the quantities are associated with i-th disk.

The space harmonics effect is taken into account by assuming that the electric field is not a simple sinusoidal function but has an experimentally observed shape.

In determining the buncher and prebuncher parameters of α and β_ω, first these equations are solved for some suitably assumed values of these parameters. Then second, inspecting the beam properties thus obtained, the parameters are modified in order to yield more desirable beam trace. This procedure is repeated until the final beam trace is obtained to satisfy required beam properties.

A typical example of the beam trace with the final α and β values is shown in Fig. 1. The first part of ξ less than 1.63 corresponds to the prebuncher, where electrons are slowly modulated to form a bunch. The following 1+1/2 λ long space is a free space, and at the end of it a bunch is roughly formed. Slow modulation in the prebuncher seems to be essential to form an appropriately bunched beam at the entrance of buncher. The bunch has a phase which is larger than zero, and this means electrons are accelerated a little, which is advantageous to make space charge less effective.

In the initial part of buncher weakly bunched beam starts to be modulated strongly to make a tight bunch. This is an important part to accelerate high current and it is necessary to keep beam orbits as parallel as possible and not intersect one another.

The final parameters are listed in Table 1. The total number of cavities is 7 for the prebuncher and 44 for the buncher both including input and output couplers. The buncher part where β is less than unity is consisting of 8 cavities, while the regular part where β is unity is of 36 cavities.

The beam phase and energy at the output of buncher are plotted as a function of the beam phase at the input in Figs. 2 and 3.

DETERMINATION OF BUNCHER AND PREBUNCHER PARAMETERS FOR FABRICATION

In fabricating the prebuncher and buncher the parameters required are cavity dimensions which are the disk diameter 2a, the spacer inner diameter 2b, the period of structure d, and the disk thickness t.

While α is defined as $\alpha = eE\lambda/m_o c^2$ as mentioned before, E is given by $E = \sqrt{2PIR}$, where P is the rf power, I is the attenuation constant, and R is the shunt impedance. The quantities I and R are both functions of 2a, so that if P and 2a values are given, E is calculated to give α. By repeating the calculation 2a values can be obtained to yield the desired values of α. The quantities P, I and R are given by

$$P = P_o \exp(-2Iz) \tag{4}$$

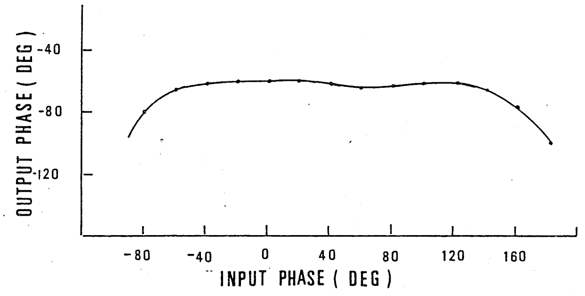

Fig. 2 Output beam phase versus input beam phase.

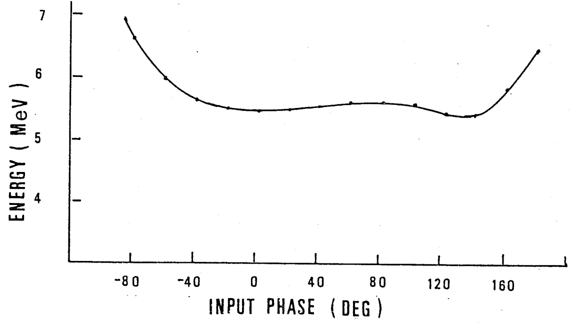

Fig. 3 Beam energy as a function of input beam phase.

Table 2. Cavity Dimensions

PREBUNCHER CAV.No.	PREBUNCHER 2a*	PREBUNCHER 2b	BUNCHER CAV.No.	BUNCHER 2a*	BUNCHER 2b
1 (+)	28.30	85.55	1 (+)	27.44	84.69
2	27.64	85.32	2	26.80	84.37
3	27.01	85.09	3	26.10	83.99
4	26.41	84.86	4	25.43	83.61
5	25.83	84.63	5	24.94	83.30
6	25.27	84.41	6	24.53	83.08
7 (+)		84.21	7	24.14	82.91
			8	23.82	82.77
			9	23.52	82.66
			10	23.45	82.61
			.	.	.
			.	.	.
			.	.	.
			43	20.94	82.04
			44 (+)		82.02

* i-th 2a is for the disk between ith and i+1th cavity

(+) The first and last cavities are couplers and have smaller dimensions than indicated

$$I = B\cdot\frac{n + 2.61\beta_\omega(1-\eta)}{a^4\beta_\omega(1-\eta)^2} \tag{5}$$

$$R = A\,\frac{\beta_\omega(1-\eta)^2}{n + 2.61\beta_\omega(1-\eta)}\left\{\frac{\sin(D/2)}{D/2}\right\}^2 \tag{6}$$

where n is $\lambda/d = 3$, the number of disks per wavelength, $\eta = t/d$, $D = 2\pi(1-\eta)/n$.

The coefficients A and B may depend on 2a but assumed not depend on β_ω, and determined by fitting experimental data currently available with the formulas (5) and (6). Thus for the given values of α, 2a values are obtained.

The determination of 2b is more complicated, because there is no reliable β dependence available, although there are sufficient data on the relation between 2a and 2b for $\beta_\omega = 1$ in a limited 2a region. Therefore, all the data available are collected and for a definite value of β_ω, these experimental points were fitted with polynomials to the 5th order. The dependence on β_ω is assumed.

The parameters thus obtained are listed in Table 2. In manufacturing the buncher and prebuncher, after assembling the disks and spacers together with the input and output couplers, rf measurements will be made of the phase shift by the plunger method and necessary corrections will be applied before electroplating these parts.

BEAM TRANSPORT SYSTEM OF INJECTOR[4]

A solenoidal magnetic field to produce Brillouin flow is most suited to transport high current beams with an energy around 150 keV from the gun to the prebuncher. Its strength B_z is given by

$$B_z = \frac{36.9}{r_b}\sqrt{\frac{I}{\sqrt{\gamma^2-1}}} \qquad (7)$$

where I is the beam current and γ_b is the beam radius as before. For I = 15 A, γ_b = 0.7 cm and γ = 1.294 (150 keV), B_z is equal to 225 gauss.

In the prebuncher and buncher where the energy is still not so high, a solenoidal field is also effective to transport these high current beams with a fairly large emittance. The field strength B_z is for the desired acceptance U,

$$B_z = \frac{6.67U}{\pi\gamma_b^{\,2}} \qquad (8)$$

for U = 0.015 πMeV/c·cm and γ_b = 0.7 cm, B_z = 0.2 kG is obtained.

At higher energies after the buncher, quadrupole magnets are more effective to focus the beam. In this case U is given by

$$U = \frac{\pi\gamma_b^{\,2}(dP/dZ)}{\ell_n(P_2/P_1)} \qquad (9)$$

where dP/dZ is the momentum gain per unit length, P_1, P_2 are the momenta at the first and the second triplet, respectively. Arrangement of focussing elements is shown in Fig. 4, and the beam envelope expected is shown in Fig. 5.

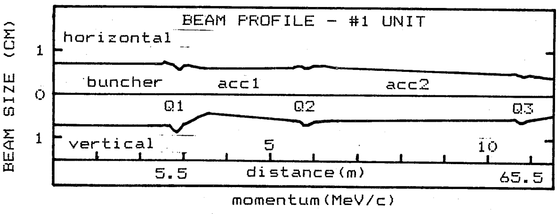

Fig. 5 Calculated beam envelope in the injector.

ELECTRON GUN, MODULATOR AND SUBHARMONIC BUNCHER

The electron gun to be used is a similar one to that used in the PF linac, with some modification to the shape of electrodes. Another gun with a grid-cathode assembly of EIMAC Y-796 is also planned for use.

The high voltage gun modulator was already manufactured, and its main parameters are as follows: The output voltage is variable from zero to 16 kV, the output impedance is 12.5 Ω. The flattop of the pulse is more than 2 μsec with a flatness of less than 0.3%. A pulse transformer with a step-up ratio of 1:12 and a high voltage station were also made.

To increase the beam current, use of a subharmonic buncher is planned, and its design has been started and now in progress.

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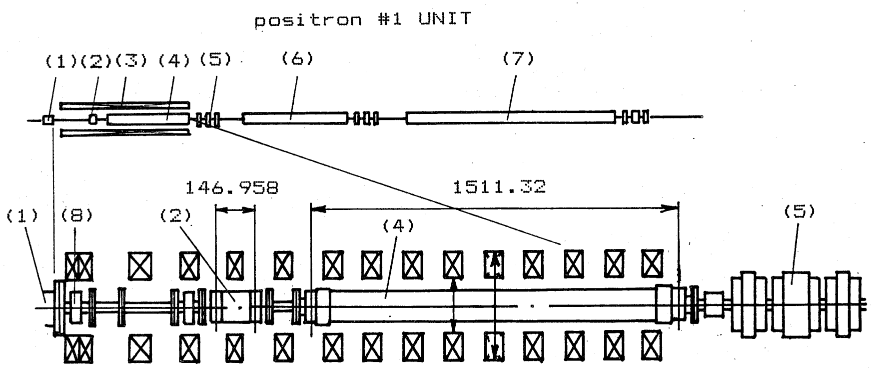

Fig. 4 Layout of injector.
(1) Electron gun, (2) Prebuncher, (3) Solenoid coils, (4) Buncher, (5) Triplet Q magnet, (6) 1st accelerator guide, (7) 2nd accelerator guide, (8) Current monitor.