THE DESIGN AND SIMULATION STUDIES OF THE PRE-INJECTOR FOR CANDLE LIGHT SOURCE

B. Grigoryan, A. Vardanyan, V. Tsakanov, CANDLE, Yerevan, Armenia

Abstract

In this report the design layout and simulation study of the pre-injector for CANDLE project are presented. The pre-injector design includes the thermionic gun and the bunch formation systems. The gun is the standard triode gun, modulated by 500 MHz amplifier, which matches the beam pulse structure to the booster and storage ring RF buckets. The downstream 500 MHz and 1 GHz sub-harmonic bunching cavities perform an additional sub-bunching of the beam which will be accelerated in the 100 MeV S-Band injector linac. The single and multi bunch modes of the pre-injector operation are considered. The simulations are performed using PARMELA and E-Gun codes.

1 INTRODUCTION

As an injector for CANDLE booster ring will be used a 100 MeV S-band linear accelerator based on the components already built for S-Band Linear Collider Test Facility at DESY [4,7]. The linac design and layout will fulfill the following basic requirements

- Single and multi-bunch operation modes;
- Nominal repetition rate 2 Hz;
- Energy spread in single pulse 0.5%;
- Pulse-to-pulse energy spread of 0.25%;
- Current injection rate at 100 MeV – 400 mA/min;
- Minimum beam losses.

The general scheme of injector complex is shown in Figure 1.

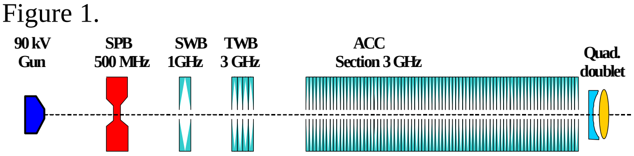

Figure1. The schematic layout of the injector linac.

The maximum duration of the single bunch at the electron gun exit is 1ns with 1.6 nC charge (~10^{10} electrons, peak current 2.2 A), while the maximum duration of the bunch train for multi-bunch operation mode is 600 nsec with maximum total charge of 6 nC (10 mA pulse current). An electron pulse from the gun modulated by 500 MHz amplifier is captured by sequentially located 500 MHz sub-harmonic pre-buncher (SPB), 1 GHz pre-buncher cavity and 3 GHz traveling wave (TW) structure. The result is the 500 MHz pulse structure with the more than 90% of beam captured in a 18^o of 3 GHz phase duration. In multi-bunch operation mode, a 480 ns long electron pulse from the linac will fill the 240 RF buckets of the booster, out of possible 320 (at 499.476 MHz). This will leave a 160 nsec for the injection kicker field to decay before the beam reaches the injection point on its second pass.

grigory@asls.candle.am

The injection energy to booster of 100 MeV corresponds to an injection field of 24 mT in the booster and is high enough to reduce the difficulties due to tune change during the ramping of the booster. The whole linac (Figure 1) consists of the gun equipment (0.7 m), a drift (0.4m), a 500 MHz buncher, a second drift (~0.15m), a 1 GHz buncher (~0.1 m), a third drift (0.1m) and 3GHz TW buncher (0.08 m). After 6 cm of drift, the beam enters into 6 m long accelerating section with the gradient of 17 MeV/m. The drift spaces are equipped with the correction coils, focusing solenoids, beam position monitors (BPM) and the screen (or wires) for beam profile detection.

2 ELECTRON GUN

The gun is the standard triode gun, modulated by 500 MHz, which matches the beam pulse structure already at the gun to the booster and storage ring RF-bucket structure avoiding the beam losses at high energy in the booster ring. A gun pulse with a length of ~ 1 nsec is obtained. The voltage between the gun cathode and anode is 90 kV. Two operating modes are considered with the pulse length of 1ns (single bunch mode) and 200-600ns (multi-bunch mode) according to the linac specification. In single bunch mode the cathode is pulsed with respect to grid. In multi-bunch mode the grid is modulated at 500 MHz with respect to the cathode. The gun is a standard EIMAC YU-171 type with the cathode emission surface radius of 5.6 mm (area-1cm^2). The main characteristic parameters of the gun are given in Table 1.

Table 1. The main parameters of the gun.

Parameters	Single bunch mode	Multi bunch mode
Cathode (YU-171) radius (mm)	5.6	5.6
Cathode-anode distance (mm)	35	35
Electron beam / pulse length (ns)	1	200-600
Trans. beam size at gun exit (mm)	6.6	4.8
Emittance at gun exit $\varepsilon_{x\ \text{norm}}$ (π mm-mrad)	10	10.25
Maximum electron current (mA)	1500	15
Electron energy (keV)	90	90
Current Density (mA / μ m^2)	20	0.3

The electron emission from cathode has been simulated by E-GUN code. Figure 2 shows the current flow in gun section for the maximum electron current of 1.5 A (single bunch mode) and 15 mA (multi-bunch mode). The normalized emittances of the electron beam at the gun exit are 10 and 10.25 π mm·mrad for single and multi-bunch operation modes respectively.

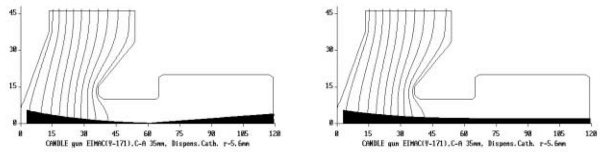

Figure 2. The electrons flow in the gun with cathode radius of 5.6mm for the beam current of 15mA (left) and 1.5A (right).

In multi-bunch operation mode at the gun exit, the 90 keV electron beam has an absolute emittance of 16 $\pi \ mm \cdot mrad$. The transverse beam size (3σ) is 4.8 mm. The beam Twiss parameters are $\alpha = 0; \beta = 14.4cm$. The output pulse full width is expected 1.2 ns with about 90% of particles located in FWHM length of 1 ns**.** The 90 keV gun pulse is guided by the 40 Gauss solenoidal magnetic field up to distance of 0.7 m. This section equipped also with correction coils, beam position monitor, valve and pumping port. Figure 3 shows the transverse beam phase space of the electron beam at the gun output.

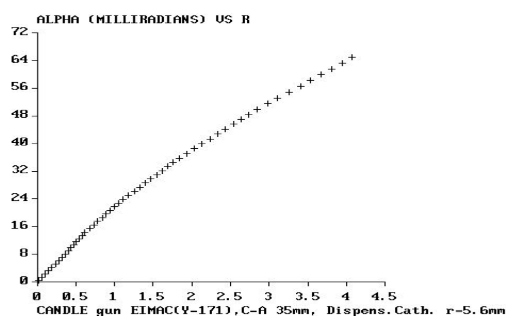

Figure 3. The beam phase at gun exit.

3 BUNCHING SECTION

The bunching section of the pre-injector consists of 500 MHz sub-harmonic pre-buncher (SPB) cavity, 1 GHz pre-buncher cavity (16 keV) and 3 GHz travelling wave structure. The SPB that is similar to buncher cavity designed for the SBLC test facility and located at the distance of 0.43m behind the gun compresses the 1 ns gun pulse to smaller rms length. In order to perform an effective velocity modulation along the pulse, the SPB cavity voltage is optimised to 30 kV across the buncher gap. The parameter list of the 500 MHz buncher cavity is given in Table 2.

Table 2 Parameter list of 500 MHz SPB cavity.

Gap aperture diameter (mm)	34
Gap length (mm)	40
Overall length (mm)	200
Diameter of cavity (mm)	350
Material	Stainless steel
Shunt impedance R (MΩ)	0.27
Q – value	2700
Voltage (kV)	30

The 6 dimensional phase space of the beam has been tracked along the bunching system. The initial beam 6-d phase space projection in all tree directions has an elliptical shape. The longitudinal phase is expanded within the –600 ÷ +600 degree of 3 GHz structure that corresponds to particle longitudinal distribution of about 1.2 nsec. The optimal bunching performance of the beam is achieved at the distance of

$$L_{bunching} = \frac{\lambda_{RF}}{2\pi} \frac{m_e c^2 \beta^3 \gamma^3}{eU_{peak}} \quad (1)$$

where λ_{RF} is the cavity RF wavelength, $m_e c^2$ is the rest energy of electrons, $\beta = v/c$, γ is the particle Lorenz factor, e is the electron charge, U_{peak} is the peak cavity gap voltage. The optimal bunching distance with given parameters of the gun and SPB is achieved at a distance of about 35 cm following the 500 MHz buncher. This is accomplished by having a significant proper velocity modulation with the positive energy-phase correlation of the particles that the head particles are slower and tail particles are faster. At the optimal bunching position, the energy-phase correlation should still having the positive slope therefore the optimal distance after the buncher has been found to be 29 cm. Figure 4 presents the longitudinal beam distributions just after the buncher and at the distance 29 cm after beam passed the buncher cavity.

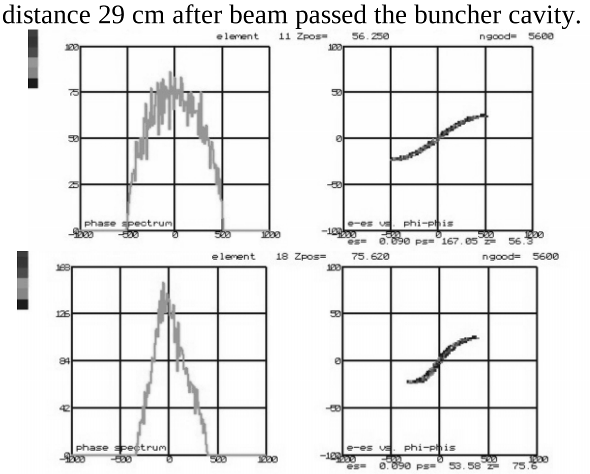

Figure 4. Bunch longitudinal distribution after 500MHz buncher (top) and at following distance of 29 cm (bottom)

The 30 kV amplitude voltage of SPB cavity provides the capture of about 50% of particles within 30° of 3GHz pulse structure.

After the 500 MHz SPB cavity, the compressed, 90 keV energy beam with more than 70% charge in one 3 GHz wavelength (10 cm) is entering to 1 GHz bunching cavity with the peak voltage of 16 kV. Actually, the second 1 GHz buncher constitutes the second harmonic of the optimal linear voltage needed for the effective bunching. The result of this buncher effect is shown in Fig. 5 (top).

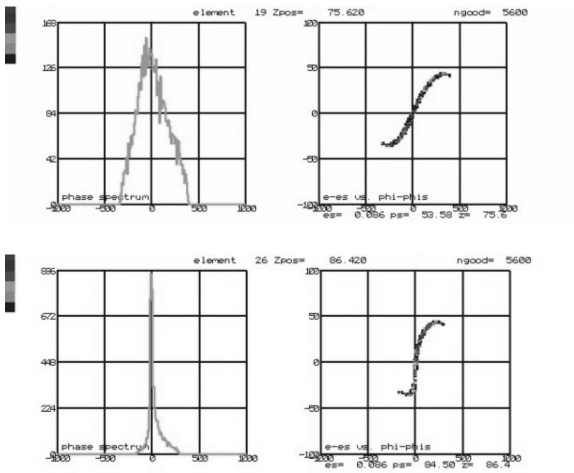

Figure 5. Longitudinal distribution after 1 GHz buncher (top) and at the entrance to 3 GHz TW structure (bottom).

The buncher cavity does not change the kinetic energy of the bunch that is still defined by the gun voltage of 90 kV, which corresponds to velocity $\beta = v/c = 0.526$. As the direct acceleration of such a non-relativistic beam in $\beta = 1$ phase velocity main S-Band structure lead to large energy spread of about 5%, one 3 GHz traveling wave (TW) structure is used for pre-acceleration and bunching purpose before the beam enters into main linac structure. The 3 GHz TW section is located at the distance 10 cm after 1 GHz buncher cavity. This is a $2\pi/3$ mode structure with a phase velocity of 0.6c and a length of 8 cm (4 cells). The input RF power is 3 MW and the gradient 4 MV/m. Figure 5 shows the beam longitudinal distributions after the 1 GHz buncher cavity and at the entrance to 3 GHz TW structure.

4 THE 100 MEV LINAC

The output current for 500 ns long electron pulse is given by the demand to fill the CANDLE storage ring within one minute to a mean current of 350 mA. Taking into account the booster synchrotron repetition rate of 2 Hz and revolution time 720 ns in CANDLE storage ring one gets

$$I = \frac{350mA \cdot 720n\sec}{60\sec \cdot 2\sec^{-1} \cdot 500n\sec} = 4.2mA \qquad (2)$$

Considering some losses in whole injection chain, a linac output current of 15 mA will be more than sufficient.

With one standard 6 m long accelerating section of SBLC type structure [4], the energy of 100 MeV is reached by beam loaded accelerating gradient of about 17 MV/m.

Table 3 Parameters of the SBLC accelerating section.

Section length, L (m)	6
Attenuation, τ (neper)	0.55
Group velocity variation, v_g % of c	4.1-1.3
Filling time, T_f (nsec)	790
Shunt impedance variation,R (MΩ/m)	45-61
Number of cells	180

The structure is the constant gradient type. The parameters of the linac accelerating section are presented in Table 3. The bunching system provides the capture of more than 90% particles by the main 3 GHz linac section with the 17 MeV/m. The final stable longitudinal particle distribution in main linac accelerating section is shown in Figure 6, which contains more 90% of particles in about 18° of 3 GHz structure.

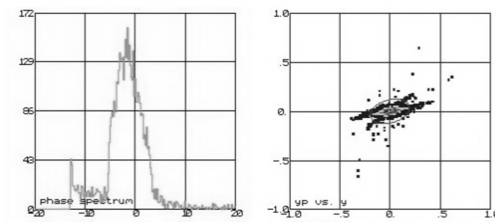

Figure 6. The longitudinal (left) and transverse (right) bunch distributions at the 100 MeV linac exit.

Figure 7 gives the number of transmitted particles along the bunching section. From initial 5600 tracked particles, only 220 particles have been lost during the whole bunching and acceleration the beam to 100 MeV of energy.

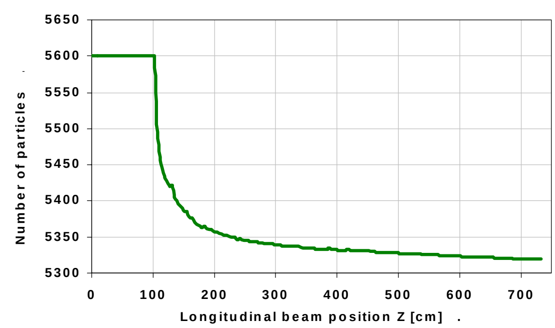

Figure 7. Number of transmitted particles along the linac.

ACKNOWLEDGMENTS

Authors express the thankful words to Michael Schmitz and Eduard Laziev for many helpful discussions.

REFERENCES

[1] R.B. Miller "An Introduction to the Physics of Intense Charged Particle Beams" Plenum Press, New York 1982.

[2] A. Chao, M. Tigner "Handbook of Accelerator Physics and Engineering" Singapore, 1999.

[3] E. Abramyan, B. Alterkop, G. Kuleshov "Intense Electron Beams" (in Russian) Moscow, 1984.

[4] M. Schmitz "Performance of the First Part of the Injector for the S-band Test Facility at DESY" Proc. International Linac Conference, Geneva, Switzerland, 1996.

[5] C. Travier " RF guns: A Review "Invited paper at the Workshop on Short Pulse High Current Cathodes, France, June 18-22, 1990.

[6] M. Schmitz "Status of the S-band Test Facility at DESY" LC'97, Zvenigorod, Russia, 1997.