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SIMULATION OF HIGH INTENSITY ELECTRON BEAM MODULAETED BY DOUBLE SHC

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Abstract A system of double subharmonic cavity (DSHC) was designed to compensate the modulated velocity by SHB. The first SHC in this system modulates the uniform velocity of the electron beam from the gun and the 2nd SHC compensates the modulated velocity in the electron beam. Intensive electron beams modulated by DSHC was simulated by a computer. The simulation include a space charge effect. It's result was given to compress the dispersed energies in the multi-bunched beam.

INTRODUCTION

The SHB(sub-harmonic buncher) was devised for the purpose of obtaining of a single bunch beam from an electron linac. [1-3] After that, the double SHB was designed for the purpose of obtaining a higher intensity beam of the single bunch, it combined with a SHB operated at a lower sub-harmonic frequency. The double SHB is succeeding in an acceleration of a single bunch beam of about 56 nC. It is reported that the energy dispersion in the intensive beams from the linac with the SHB expanded at both of a single bunch operation and a multi bunch operation. [4-5] This energy dispersion can decrease by using ECS (energy compression system). ECS device over the GeV energies becomes with large-scale and comes expensive. Therefore, we devised a new double SHC (DSHC namely) for the energy dispersion decreasing in the final electron beams. A simulation for DSHC was done by using a computer. The result gives this method is effective to the decreasing of the energy dispersion.

SHB AND DSHC SYSTEM

A popular electron linac with a SHB system is composed of an electron gun, subharmonic buncher, a prebuncher section, a buncher section and regular accelerator sections. The formation of a bunch beam in this linac is prepared through the next process. On positive voltage of a short pulse being added to a grid of the gun, an electron beam like a cord is emitted from the cathode. If the definite negative voltage adds to the electron gun, electrons in the beam is accelerated to the uniform velocity. When the electron beam passes through the SHB, it's velocity is modulated by the electric field of the SHB's cavity. The electron beam is compressed by the modulation during it advancing a drift space. The bunched electron beam is compressed tightly again by both rf field of the prebuncher and the buncher. The electron beam is whether a single bunch or multi bunches, it is due to whether shorter bunch length or longer bunch length than a wave-length of operating frequency on prebuncher. Figure 1 shows a block diagram of an ordinary linac with a single SHB system.

The DSHC system is located between the electron gun and the pre-buncher as well as the linac with a single SHB system. The system consists of two cavities. The cavities is operated individually by the same subharmonic frequency or the different. Each electric fields in the first cavity and the 2nd cavity are excited quite the opposite phase angle for the electron beam frame. The first cavity modulates an uniform velocity of electron beam from an electron gun and the 2nd cavity compensates the modulated velocity in the electron beam. Figure 2 shows a block diagram of a linac with the DSHC system.

DISCUSSION AND SIMULATION

On operation of high intensity beams from a linac with a single SHB, the energy dispersion in electron beam expands. It shows a similar tendency in either beams of a single bunch and multi bunches. We thought that spread energies in the beam at the single bunch operation is caused by the heavy beam loading in the accelerator guide, and that the spread energies at the multi bunch operation is caused by two factors. The one is due to the velocity spread in the electron beams modulated by the SHB, the other is due to the beam loading as described. Velocity modulation in electron beam by SHB is similar to modulate an accelerating voltage of electron gun. It is popular that a variation of electron gun voltage shift a phase angle on an accelerating field frame of electron beam from the end of linac.

The fact can be proved easily by simulation as a beam trace on a linac. We infer as velocity spread in electron beams on a beginning section in a linac may disperse phase angles of electron beams from the final section.

Accelerating phase angle dispersion in electron beam from a linac is equal to energy dispersion in the final electron beam. The first SHC performs a part of a bunch compression for an electron beam and the 2nd SHC performs a part of a compensation for modulated velocity in the electron beam. Accordingly, the bunch intervals among electron beams becomes equal by this method.

When each bunch in electron beam is at a low charge density respectively, the beam trace formation is very simple as given in (1)-(4)

$$\gamma = \frac{(GV + VSHB \sin\theta_o)}{m_o c2} + 1.0 \qquad (1)$$

$$\frac{d\gamma}{d\xi} = (\gamma - \alpha \sin\theta_1) \qquad (2)$$

$$\frac{d\theta}{d\xi} = 2\pi\left(\frac{1}{\beta\omega} - \frac{1}{\beta e}\right) \qquad (3)$$

$$\beta e = \frac{(\gamma^2 - 1.0)^{1/2}}{\gamma} \qquad (4)$$

where GV and VSHB are the gun voltage and the RF voltage in the SHB, θ_o is a phase angle in the SHB as given by $\theta_o = 2\pi z/\lambda_o$ and l_o is a wave length of the SHB frequency f_o as given by $\lambda_o = c/f_o$, $m_o c^2$ is the electron rest mass energy, a is electric field strength normalized by electron rest mass energy as given by $\alpha = E_o\lambda / m_o c^2$, q_1 is a phase angle of accelerating field as given by $\theta_1 = 2\pi z/\lambda$, λ is a wave length of accelerating frequency, ξ is the length normalized by the wave length as given $\xi = z/\lambda$, E_o is the electric field strength in an accelerator guide, and βw and be give respectively a phase velocity and an electron velocity normalized by the light velocity as $\beta w = v_p/c$ and $\beta e = v_e/c$.

Whenever each bunch in electron beam is at a high charge density respectively, the beam trace formation complicates because of the space charge repulsion. The effect of this repulsion is expressed as (5) by use of the disk model. [6] It's effect adds to (2).

$$sc=\frac{2e\lambda^2 I_n}{m_0 c^2 \pi b^2 N}\sum_{j=0}^{N}\sum_{n=1}^{m}\left(\frac{J_1\left(\frac{\beta_{on} b}{a}\right)}{\beta_{on} b \quad J_1(\beta_{on})}\right)^2 \frac{e^{-\left(\frac{\beta_{on} \quad \beta_w \lambda\{\delta_i-\delta_j\}}{2\pi a}\right)}}{\gamma_j^2} \qquad (5)$$

where δ_i is phase of ith disk, γ_i is energy of disk, N is number of disks In is equivalent DC current of beam (I=Nq), a and b are pipe and beam radii respectivivly, and β_{on} is successive zeroes of the zero order Bessel function of first kind (J_1).

The first beam trace was performed in the section from the entrance of single SHB to the exit of buncher's section. This trace is simulated by use of the equation (1)-(4). The result is shown in figure 3. The trace refered to the parameters of injection section in the positron generator linac in the PF injector, and the parameters show in table 1. The trace in the figure 3 shows that the intervals of the final phase angle do not uniform for individual bunches.

The next trace was performed for searching the effect of DSHC system. It's trace was done in the section from the entrance in the system to the exit of buncher's section by use of the same parameter. This result is shown in figure 4. The trace in the figure 4 shows that interval of each phase angle uniform in the multi-bunches.

Table 1 Design Parameters of Injection Section in KEKPositron Generator

Gun Voltage	200 KV
SHB Freguncy	119 MHz
Harmonic numbers	24

Prebuncher			Buncher section		
Cavity numbers	α	β	Cavity numbers	α	β
1	0.036	0.7	1	1.37	0.78
2	0.038	0.7	2	1.43	0.80
3	0.040	0.7	3	1.50	0.83
4	0.042	0.7	4	1.58	0.87
5	0.044	0.7	5	1.66	0.91
6	0.046	0.7	6	1.72	0.945
7	0.048	0.7	7	1.77	0.965
8	0.050	0.7	8	1.82	0.983
			9	1.86	1.0
			10-18	2.0	1.0

Intensive electron's charge compressing in a short pulse beam induces a strong repulsion force action in it's bunch. This force action prevents the bunch action of SHB. Those actions may balance themselves under the some specfications in the linac's parameters. There may be a ballance point in the drift section between the single SHB and the prebuncher's entrance. The energy dispersion in this electron beam becomes small at this point. If prebuncher's section is set up at the point, the interval of the phase angles will uniform for individual bunches.

Accordingly, the beam trace must calculate under the consideration of the space charge repulsion. The trace was simulated by use of the equations (1)-(5). The simulation were done for the both of single SHB system and DSHC system. These results are shown in figure 5 and 6. The beam loading effect within this simulationsin was excluded from the traces because of a simple comparision for the space charge effects.

ACKNOWLEDGEMENTS

We are appreciated to Dr. M.Oyamada for his effort programing a calculation code with space charge effects.

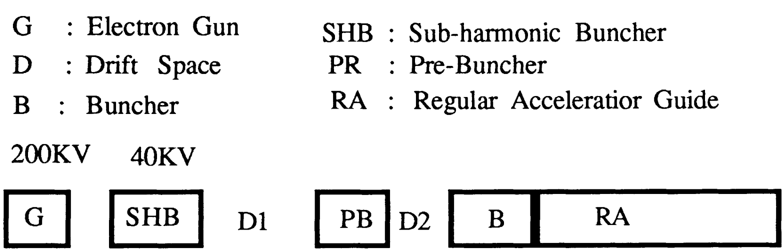

Figure 1. Block diagram of injection section in an electron linac with a single SHB system.

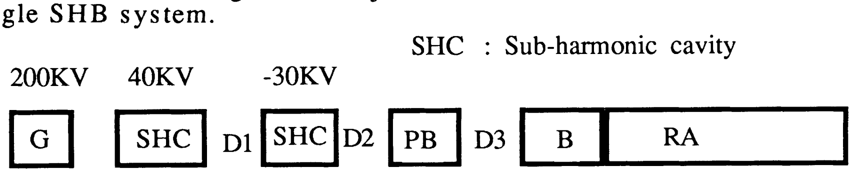

Figure 2. Block diagram of injection system in an electron linac with double SHC systems.

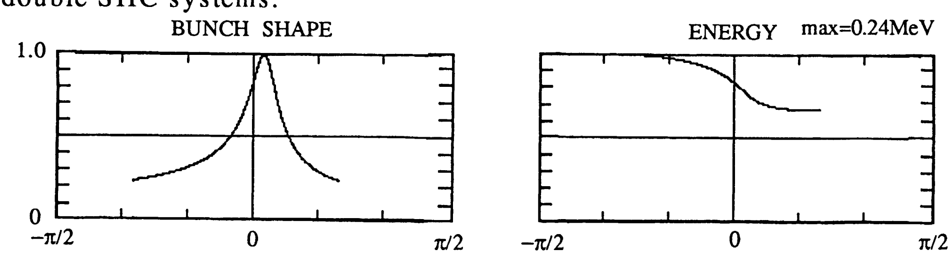

Figure 3(a). Simulated bunch shape and energy disparsion in electron beam which is modulated by a single sub-harmonic buncher. The beam trace was done from the gun to the drift space in a single SHB.

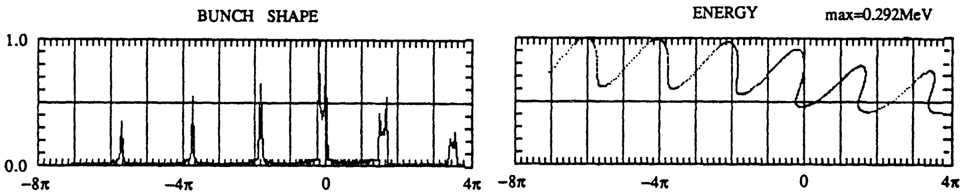

Figure 3 (b). Simulated energy dispersion in a buncing electron beam which is modulated by a single sub-harmonic buncher.

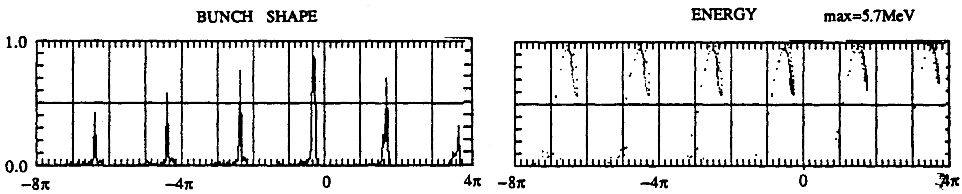

Figure 3 (c). The bunch shapes and the energy dispersions in electron beams which is traced from the gun to the buncher section with the single sub-harmonic buncher.

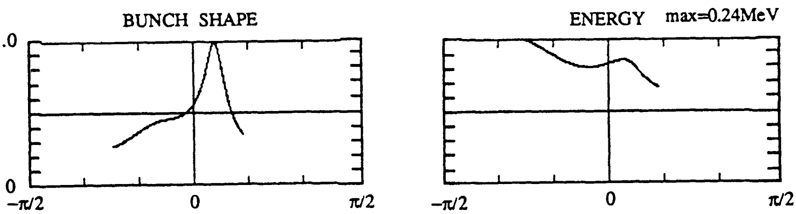

Figure 4(a). Simulated bunch shape in electron beam which is modulated by double subharmonic cavities.

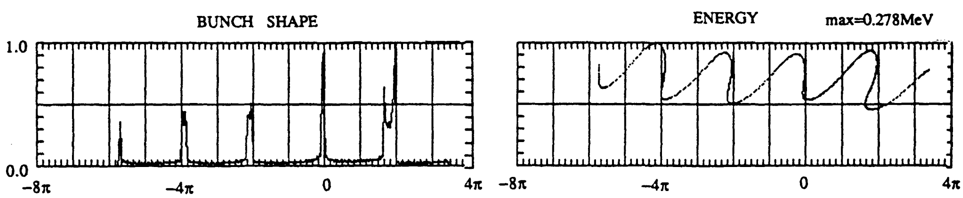

Figure 4(b). Simulated energy dispersion in a buncing electron beam which is modulated by a single sub-harmonic buncher.

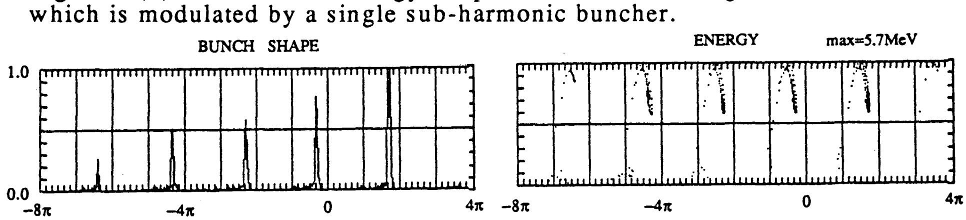

Figure 4 (c). The bunch shapes and the energy dispersions in electron beams which is traced from the gun to the buncher section with the double sub-harmonic cavities.

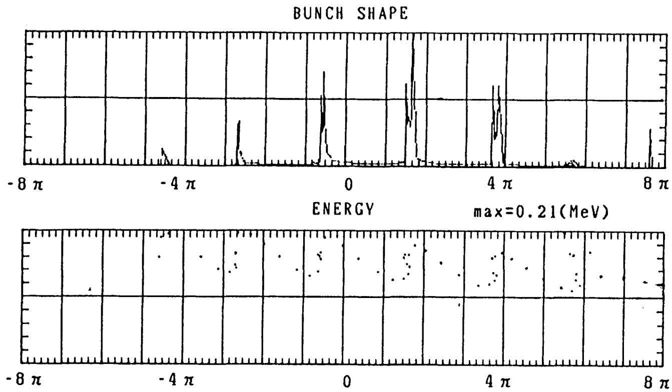

Figure 5. Bunch shapes and energy dispersions in the electron beam which was modulated by a single SHB. This profiles were traced from the gun to the drift space end in the prebuncher section by the simulation code with the space charge effect.

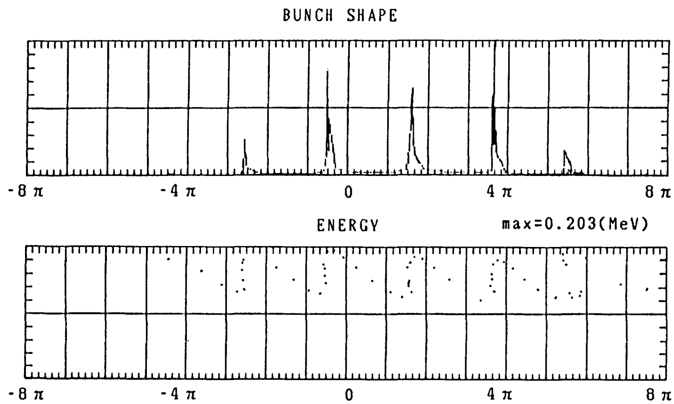

Figure 6. Bunch shapes and energy dispersion in the electron beam which was modulated by double subharmonic cavities. This profiles were traced by the same simulation in the figure 5.

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