TRAVELING WAVE ELECTRON LINAC FOR SYNCHROTRON INJECTOR

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Abstract

In this paper the project design of a traveling wave electron linac which can be used as an injector to synchrotron in Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS) is presented. The injected beam to the synchrotron should have very small emittance and energy spectrum. Thus, the buncher design is an essential question in this problem. One of the best output beam parameters can be achieved by using a waveguide buncher with the non-uniform parameters. The proposals of optimal buncher design and beam dynamics calculation results are presented.

INTRODUCTION

The beam injected to the electron synchrotron should have very small transversal and longitudinal dimensions and also a very narrow energy spectrum (~0.5%). Particularly, the one installed in LPI must have the following parameters [1]:

Table 1: Technical Characteristics for the Injector

Parameter	Value
Average output energy, MeV	20±1
Pulse beam current, mA	50±10
Pulse length, μs	2...4
Pulse repetition frequency, Hz	0.5...10
Operating frequency	C- or S-band
Energy spectrum, %	≤0.5

Either RTM or linac can serve as an injector to this synchrotron. In this paper the proposal of electron linac is made. First, the klystrons power and frequency are chosen, then the accelerating structure is proposed, and finally, the waveguide buncher parameters are optimized.

ACCELERATING STRUCTURE

The preliminary estimations [2] were done for accelerating structure either with constant impedance or gradient, and klystron parameters for π/2 or 2π/3 DLS-based traveling wave linac have been chosen. Four klystron's output pulse power at operating frequencies 2856 or 5712 MHz have been regarded. The optimal parameters for both frequencies are presented in Table 2.

The final choice was made for 5712 MHz frequency range as it has higher efficiency and bigger aperture radius which means the higher manufacturing tolerances. Also, the C-band linac is shorter, but this parameter is not crucial for injector to synchrotron.

Table 2: Estimated Linac Characteristics

Parameter	Value	
Operating frequency, MHz	2856	5712
Operating mode, rad	2π/3	
Structure type	constant gradient	
Input pulse power, MW	6.0	
Normalized aperture radius (a/λ)	0.07	0.08
External magnetic field, Oe	1200	
Structure length, m	3.5	3.0
Efficiency, %	30	40

BUNCHER OPTIMIZATION

Initial Parameters

The optimal capture can be achieved while varying the parameters of a buncher. One of the most popular buncher types are those with the variable phase velocity, because they have better bunching performance than the other ones. The electron dynamics in such section depends on the particle's initial energy, electric field strength and an equilibrium phase values. The beam dynamics analysis for various structures has shown [3] that for the better bunching, one should choose small values of phase velocity and the equilibrium phase value close to zero. It is necessary to avoid dramatic variations of field amplitude ($A=eE\lambda/W_0$) and phase velocity ($\beta_w=v_w/c$). The characteristic β_w (z) should have a region parallel to z-axis and at the end of the buncher, the phase velocity is chosen so, that a bunch shifts to the crest of the accelerating wave. If these conditions are met, the following acceleration would be more effective. Though it is nearly impossible to obtain the optimal functions A(z) and β_w(z) analytically, the experimental formulae have been found to satisfy the specified conditions for a given accelerating gradient A_m[3]:

$$\beta_w=(2/\pi)*(1-\beta_0)*atan(k_1\xi^{k2})+\beta_0 \quad (1)$$

$$k_1=3.8*10^{-3}*(10.8^{Am}-1) \quad (2)$$

$$k_2=1.25*A_m+2.25 \quad (3)$$

$$A=k_3-k_4*cos(\pi\xi/k_5) \text{ for } 0<\xi<k_5 \quad (4)$$

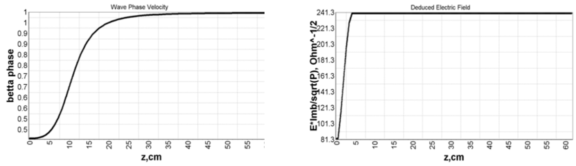
$$\text{else } A=A_m$$

$$k_{3,4}=0.5*A_m\pm0.15*A_m^{1/2} \quad (5)$$

$$k_5=1/(1.25*A_m^{1/2}) \quad (6)$$

Unfortunately these formulae have been obtained to reach the maximum capture coefficient, but the minimal energy spectrum width is required for the injector being developed. Thus, it is necessary to find the optimal buncher parameters by numerically simulating the beam dynamics for the different dependencies of $A(z)$ (or $\Lambda=E\lambda/P^{1/2}$) and $\beta_w(z)$.

All simulations have been done using the *Hellweg2D* code [4]. The initial dependencies have been obtained using the formulae (1-6) and are presented in Fig.1.



a) Phase Velocity *b) Field Strength*

Figure 1: Accelerating wave parameters distribution along the buncher.

Electric Field Dependency Optimization

First of all the optimal field strengths in the first bunching cells have been found. The field strength in the first accelerating cell remained constant Λ=240 kV/MW$^{1/2}$. For the optimization parameter, the ratio E_0/E_{end} was used (see Fig.2).

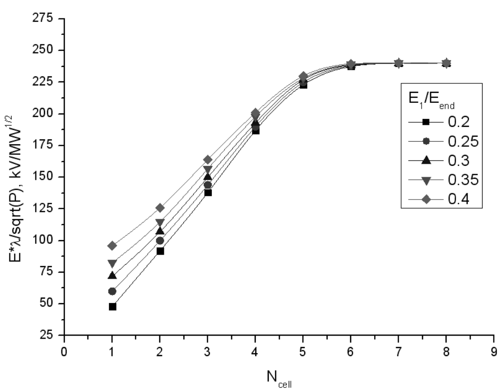
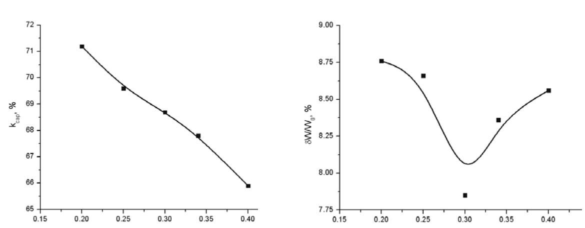


Figure 2: Electric field amplitude distribution along the buncher.

The simulation results are presented in Fig 3. Considering this data, the following conclusions can be done. Reducing the field level in the first cells it possible to achieve the higher capture coefficient. Thus, the optimal value of E_0/E_{end} is 0.2.



a) Particles captured, % *b) Energy Spectrum, %*

Figure 3: Beam parameters vs. E_0/E_{end}.

Next, the optimal field growth in the first bunching cells have been found. For the optimization parameter, the ratio $\Delta\Lambda/\Delta L$ was used (see Fig.4).

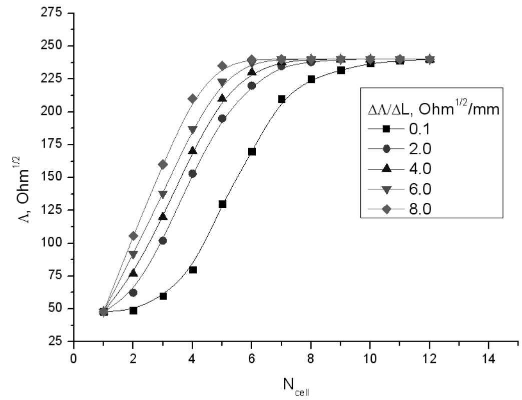
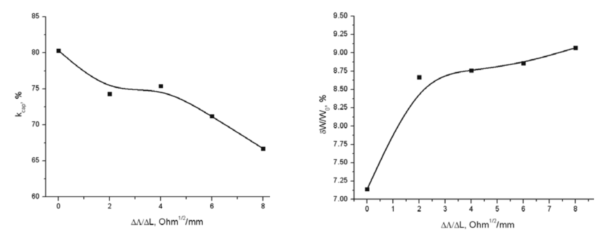


Figure 4: Electric field amplitude distribution along the buncher.

Fig 5 presents the simulation results are presented in., The following conclusions can be done considering this data. Reducing the field growth in the first cells it possible to achieve the higher capture coefficient and lower energy spectrum values. Thus, is reasonable to have the lowest $\Delta\Lambda/\Delta L$ value.



a) Particles captured, % *b) Energy Spectrum, %*

Figure 5: Beam parameters vs. $\Delta\Lambda/\Delta L$

Finally, the optimal field growth in the buncher center has been found. For the optimization parameter, the ratio $S=\Delta\Lambda/\Delta L$ was used (see Fig.6).

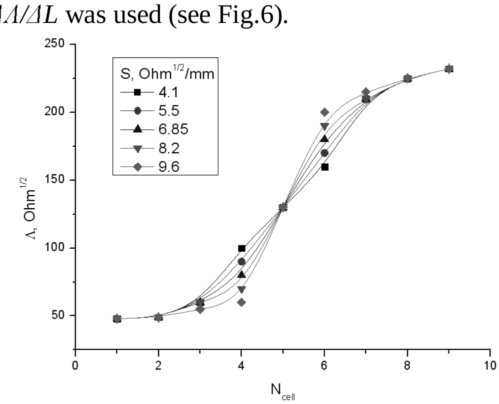
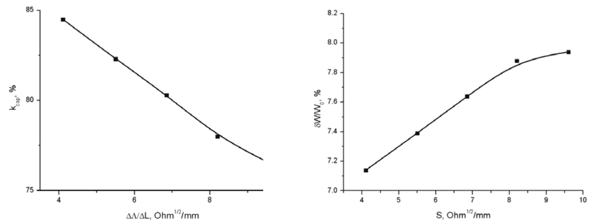


Figure 6: Electric field amplitude distribution along the buncher .

The simulation results are presented in Fig 7. Considering this data, the following conclusions can be be done. Reducing the field level in the first cells it possible to achieve the higher capture coefficient.

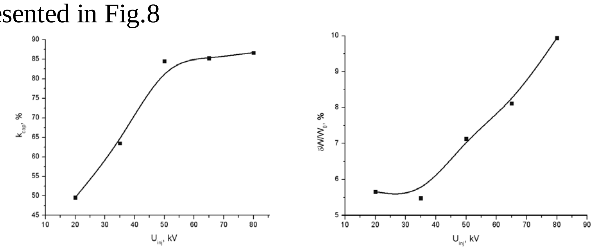


a) Particles captured, % *b) Energy Spectrum, %*

Figure 7: Beam parameters vs. *ΔΛ/ΔL*.

Further Optimization

Though, the optimal electric field dependency has been found, the output energy spectrum is far from the technical demand (Table. 1). Further reduction of this parameter is possible by varying the injection energy. The simulation results for different injection energies are presented in Fig.8



a) Particles captured, % *b) Energy Spectrum, %*

Figure 8: Beam parameters vs. injection energy

Reducing the injection energy helps to achieve lower energy spectrum values but the capture coefficient falls dramatically. The optimal results are achieved when the electrons are injected with 35 kV energy.

Now, it is necessary to optimize the wave phase velocity along the structure. It was done by making it equal to the beam velocity (see Fig.9). This optimization helped to reduce the energy spectrum width to 2.54% and to increase the capture coefficient up to 70%.

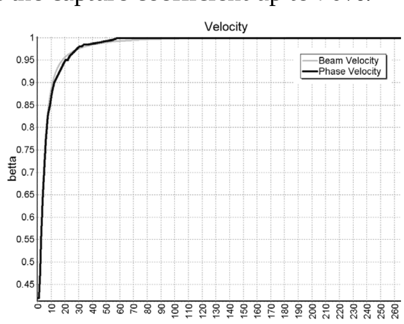


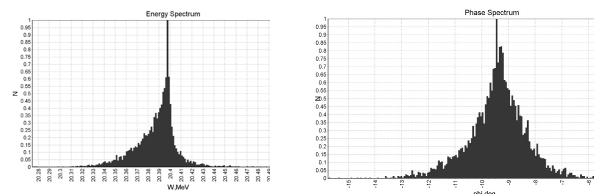
Figure 9: Phase velocity (blue) and beam velocity (green) dependencies.

To achieve the output energy spectrum down to 0.5%, it is proposed to use a chopper with a 90° phase length beam at its output. The simulation results for the accelerator with such a chopper are presented in Table 3.

The energy and phase distributions among the particles are presented in Fig.10.

Table 3: Output Linac Parameters

Parameter	**Value**
Average output energy, MeV	20.1
Pulse beam current, mA	60
Input power, MW	6.0
Injection energy, kV	20
Structure Length, m	3.07
a/λ at the end of the structure	0.08
Energy spectrum, %	0.38



a) Energy spectrum, % *b) Phase spectrum, %*

Figure 10: Particle distributions at the end of the structure

CONCLUSIONS

The traveling wave electron linac for beam injection into LPI synchrotron has been developed. The DLS-based $2\pi/3$ accelerating structure with constant gradient and the klystron with 6.0 MW pulse output power operating at 5712 MHz frequency have been chosen.

In order to achieve the energy spectrum value of the output beam less than 0.5%, the waveguide buncher with the variable parameters has been developed.

REFERENCES

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