BEAM DYNAMICS SIMULATION RESULTS IN THE 6 GEV TOP-UP INJECTION LINAC OF THE 4TH GENERATION LIGHT SOURCE USSR

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Abstract

The new project of 4th generation synchrotron light source USSR (Ultimate Source of Synchrotron Radiation, early known as Specialized Synchrotron Radiation Source, SSRS-4) is under development today. It was proposed that USSR will include both storage ring and soft FEL and one linac will used for injection in synchrotron and as a bunch driver for FEL. The general concept of the top-up linac is proposed and the beam dynamics was simulated. It is suggested to use two RF-guns in this linac similar to Super-KEKB, MAX-IV and CERN FCC. One of the RF-guns should be classical with thermionic cathode and will be used for injection into storage ring. The second one having photogun will use to generate a bunch train for FEL. Current results of the top-up linac general scheme development and first results of the beam dynamics simulation will present in paper.

INTRODUCTION

Starting 2017 the new project of 4[th] generation synchrotron light source called Specialized Synchrotron Radiation Source (SSRS4) is under development in Russia. Current version of SSRS4 general layout includes 6 GeV main storage ring and top-up injection linac. Free-electron laser will also include in SSRS and top-up linac will used both for injection in the storage ring and for generation of the drive beam for FEL. Such layout leads to two linacs operation modes: 6 GeV beams for injection and 6-7 GeV high-brilliance bunches for FEL. It leads to the same for-injection scheme as it was used for SuperKEK-B and MAX-IV and is proposed for FCC-ee [1-2]: two RF-guns with photocathode and thermionic cathode and one main linac with large number of identical regular sections (see Fig. 1).

The conceptual design of new linac is now under development. The top-up injection scheme into SSRS4 main storage synchrotron is preferable. Thus it is proposed to use the same linac with two RF-guns. First of them will photogun and can be used to generate the drive beam for FEL. The second one will RF-gun with thermionic cathode can be used for injection in to storage ring. Both injectors will work with the same regular part of the linac which consists of 80-90 identical sections.

The possible layouts of SSRS4 injection linac are shown in Fig. 1. Let us present results of the beam dynamics simulation for photogun, RF gun with thermionic cathode and for the regular part also. The RF power requirements for linac will be also briefly discussed.

The planning storage beam current for the main ring will be close to 200 mA and the single bunch injection scheme is discussed as the main propose. But for FEL we need to generate a train of bunches to realize the effective generation, in SASE mode for an example. This demand leads to the one specific need for the linac section – the beam loading should be not sufficiently influences to the output beam energy in the bunch train. This effect will limit the bunch charge generated on the photocathode. For example, the train can consists of 10-12 bunches with the charge of 200-250 pC or of 20-300 bunches with the charge of 100 pc, but in not consists of 10 bunches with 1 nC charge. The operating frequency was chosen equal to 2856 MHz.

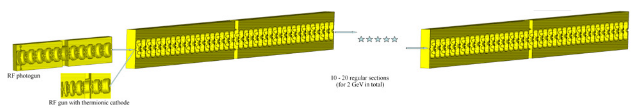

Figure 1: Possible scheme of the linac layout (RF gun with thermionic cathode is an option for high intensity drive bunches production for e^-/e^+ conversion).

BEAM DYNAMICS IN PHOTOGUNS

The beam dynamics simulation was done both for RF-guns and regular section using the BEAMDULAC-BL code [3-5]. This code was developed at MEPhI for beam dynamics simulations in RF linacs and transport channels. It has modular structure and a number of routines to solve different tasks: initial particles distribution (uniform, Gauss, KV, waterbag, etc.), motion equation integration (4[th] order Runge-Kutta method), beam emittance and other output beam parameters calculation, post processing and other. The code package has versions that take into account own space charge effects: both Coulomb part and RF part (beam irradiation and beam loading) self-consistently. The BEAMDULAC-BL code version was designed to study the beam dynamics in high-intensity electron linacs, it is discussed in detail in [5] and it was tested for a number of e-linac designs [6-9].

The beam dynamics simulation in the RF-photogun shows that 250 pC and 10 ps bunch can be easily accelerated by 5.5-cell accelerating structure with comparatively low accelerating gradient of 600 kV/cm. The current transmission coefficient is close to 100 % here and RF field amplitude of 600 kV/cm is quite enough to have 10.5 MeV after photogun. The bunch energy spread FWHM is about ±1 % (or ±300 keV). The optimization of the ptotogun structure was also done and

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the optimal choice of the cell's number was performed. It was shown that 5.5-cell gun give us minimal energy spectrum and can operates with comparatively low RF-field amplitude of 600 kV/cm. Beam loading effect is not sufficient here: one 250 pC bunch decreases RF field amplitude less than 0.15 % and such beam loading can be easily compensated by RF feed system or ignored. Transverse focusing can be effective using solenoid of 0.1 T on axis. The results f beam dynamics simulation for this photogun are presented in Fig. 2.

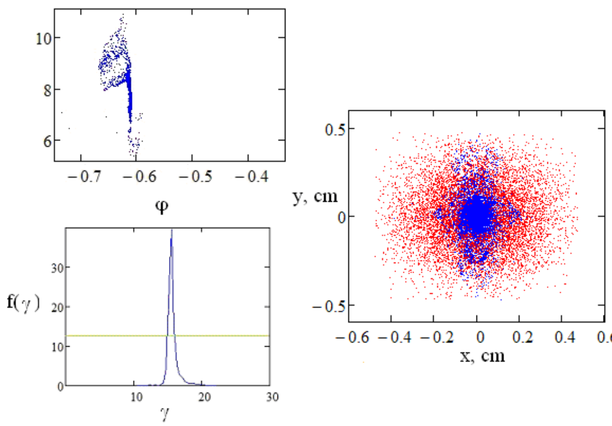

Figure 2: Phase portraits and energy spectrums (initial by red, output by blue) for photogun, E_z=600 kV/cm, bunch charge 300 nC, uniformly initial phase distribution.

BEAM DYNAMICS IN RF-GUN WITH THERMIONIC CATHODE

The beam dynamic simulation for pre-injector with thermionic gun was done also using the BEAMDULAC-BL code. This section consists of 26 accelerating cells and 25 coupling cells, it's length is equal about 140 cm. The length of 21 accelerating cells is equal to ~40.4 mm, but the last cell's length is enlarged to 52.4 mm due to the absence of coupling cell after them. First for cells are the bunching cells and the phase velocity and the RF field amplitude growth here cell-to-cell. The optimal injection energy was chosen equal to ~120 keV. The maximal accelerating field was limited by the value of 150 kV/cm on the accelerator's axe and the maximal energy is 10.5 MeV here and output energy spectrum is near ±1.5 % FWHM. The focusing solenoid with low field of 0.03 T is used to provide the beam transverse stability.

THE RESULTS OF THE BEAM DYNAMICS SIULATION IN THE REGULAR SECTION

Two types of regular sections were considered to use it in SSRS4 injection linac. The classical TW SLAC-type structure was the first one. It has 305 cm of length and 84 accelerating cells. Such section give us the energy gain ~91 MeV/section and 66 sections will necessary to achieve the energy of 6 GeV. The energy spectrum is traditional for TW structure – it is not better than $\delta W/W$~2.5 % here. Simulations show that such section can't be effectively used for injection due to such value of the energy spread which will leads to the low injection efficiency.

The other problem of TW accelerating structures is the lower RF efficiency comparatively with the standing wav like biperiodic accelerating structures (BAS). The second discussed section was BAS consists of 40 accelerating and 39 coupling cells with very high coupling coefficient close to 12-15 %. This section has 210 cm of length and the regular part of the linac will consist of 86 accelerating sections to achieve the necessary energy of 6 GeV. The averaged energy gain will equal to ~71 MeV/section. Comparatively low energy spectrum is observed for the accelerated part of the bunch. The relative spectrum $\delta W/W$=±0.9 % FWHM. The start-to-end beam dynamics simulation show that the current transmission coefficient is not so high here: K_T≈27 % The beam dynamics simulation results are illustrated in Fig. 3.

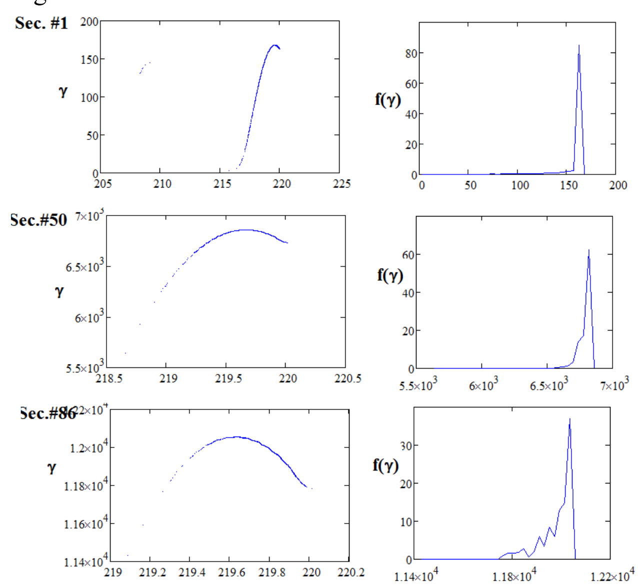

Figure 3: Beam dynamics simulation results for 40-cell BAS and 250 mA bunches: longitudinal phase spaces on the (γ, z) phase plane and energy spectrums.

The beam parameters as the geometrical length of the bunch can be reduced and the energy spectrum can be decreased if we use the short klystron-type pre-buncher before gentle buncher operating on the half-drequency of 1428 MHz. It was shown that such scheme allows us to control both these parameters using different lengths of short buncher and the different RF field amplitude. Such scheme also provide us also to generate bunches with different geometrical lengths or spectrum. As it is clear from Fig. 4, we can provide shorter bunches with higher energy spread (~5 mm and $\delta W/W$≈±0.25 % FWHM) or lower energy spread with higher bunch length (~15 mm $\delta W/W$≈±0.14 %). The current transmission coefficient (front-to-end) is higher for such scheme and achieve ~40 %. All particles losses are observed in the gentle buncher (~40 %) and the first regular section (~10 %).

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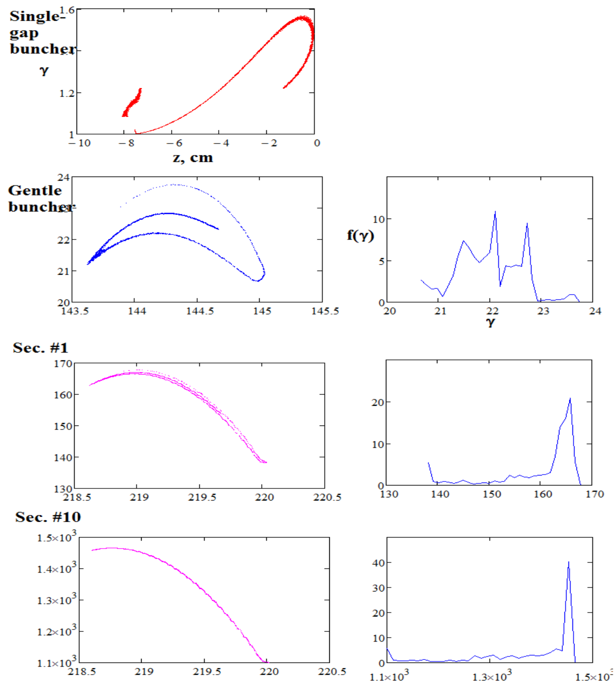

Figure 4: Beam dynamics simulation results for 40-cell BAS and 250 mA bunches, the single-gap buncher was installed before the gentle bunching section.

The beam dynamics simulation in the regular part of the linac was also performed for bunches generated by ptotogun. Results of simulation show that the energy spectrum for 250 pC bunch will be very low and it is equal to δW/W~0.08 %. The current transmission coefficient here is ~99.5 %. Beam dynamics simulation results are presented in Fig. 5 for this case.

RF POWER REQUIREMENTS

The "realistic" RF power feed scenario for the regular part is discuss now. We chose the RF-field amplitude in the center of accelerating cells equal to E_z=600 kV/cm and results of RF power requirements analysis are presented in Table 1 for this case. It is clear that the SW structures give us higher relation of the energy gain and necessary RF power. If we will use the SW structures with high value of coupling coefficient (10-12 % for BAS and up-to 30-40 % for the improved structures as disk-and-washer, DAW), we can sufficiently reduce the RF filling time. The SLED or any other energy compressor with the boost factor of K_{RF}=6-8 can be used because of the short current pulse (250 or 500 ns) and low transient time (~200-300 ns which was realized in a BAS with factor of 10-12 %, [8]). Thus we can use one klystron with RF compressor to feed 4-6 regular BAS sections comparatively 2 SLAC-type sections.

Additional control system for the SLED phase switches should be used to yield necessary RF pulse shape after compression. In the classical SLED RF pulse will have a droop, but it is unusual for long current pulse because it leads to droop of bunch-to-bunch electron energy. A number of droop compensation schemes were proposed and successfully realized. But for FCC-ee injection linac we will have very specific problem to develop the compensation solution taking into account two regimes of the beam loading: pC bunches for injection and drive nC bunches for e-/e+ conversion.

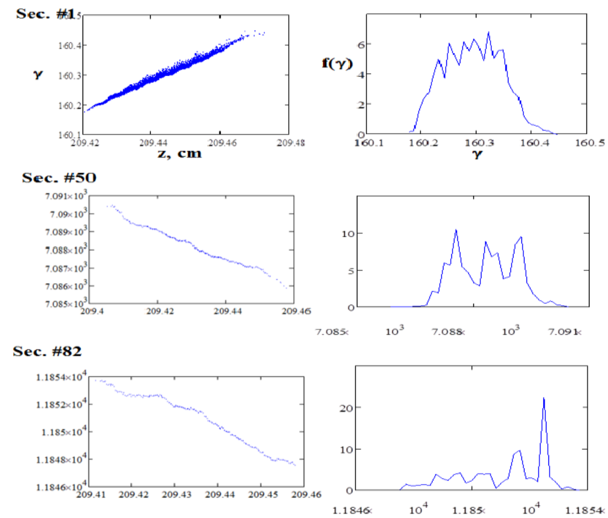

Figure 5: Beam dynamics simulation results for 40-cell BAS and 250 pC bunch generated by the photogun.

Table 1. RF Power Requirements for One Regular Section: P, MW/ W_{sec}, MeV/ L_{sec}, m (Compression with k_{RF}≈4)

Ez, kV/cm	SLAC	BAS	DAW
400	80/60/3	40/50/2	40/55/2
500	120/75/3	70/60/2	70/70/2
600	150/90/3	100/70/2	100/80/2

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CONCLUSION

As it was shown by the numerical simulations that one linac can be used both for injection into storage ring of SSRS4 (or USSR) and for FEL. It was proposed to use high-efficiency BAS (or DAW) structures in regular part of the linac and 84 regular sections are necessary to achieve the output energy of 6 GeV. The bunch size and the spectrum can be controlled for both types of bunches (generated by photogun and RF-gun with thermionic cathode).

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