STUDIES ON AN S-BAND BUNCHING SYSTEM WITH HYBRID BUNCHER

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Abstract

Generally, a standard bunching system is composed by a SW pre-buncher, a TW buncher and a standard accelerating section. However, there is one way to simplify the whole system to some extent by using the Hybrid Buncher, which is a combined structure of the SW pre-buncher and the TW buncher. Here the beam dynamics studies on an S-band bunching system with Hybrid Buncher is presented, simulation results shows that similar beam performance can be obtained at the linac exit by using this kind of bunching system rather than the standard one. In the meantime, the structure design of the Hybrid Buncher is also described. Furthermore, the standard accelerating section can also be integrated with the Hybrid Buncher, this can further simplify the bunching system and lower the construction cost.

INTRODUCTION

A standard bunching system is usually composed by a standing wave (SW) pre-buncher (PB), a travelling wave (TW) buncher and a standard accelerating section. However, for various reasons and different applications, the bunching system is often simplified to lower the construction cost or complicated to enhance the beam performance. In the industrial applications, the PB and buncher are often eliminated but the first few cells of the standard accelerating section are modified with gradually increasing phase velocity β; in the scientific applications, one or more Sub-harmonic Bunchers (SHB) are usually introduced into the bunching system or used to replace the PB. The former is commonly accompanied with degraded beam performance; while the construction cost of the latter is relatively higher.

IHEP is constructing a 100 MeV / 100 kW electron linac (625 Hz / 2.7 μs / 600 mA) with standard bunching system for the Kharkov Institute of Physics and Technology of National Science Center (NSC KIPT, Kharkov, Ukraine) [1]. Initially, the buncher is a 4-cell TW constant impedance (CI) structure with β=0.75. However, the adoption of water cooling jacket to bring away the high average RF power dissipated on the structure wall demands more longitudinal space (leading a longer buncher) to ease the installation. Finally, a 6-cell version was developed.

Inspired by the innovative idea of the hybrid photo-injector developed by the INFN-LNF/UCLA/SAPIENZA collaboration [2], we propose an alternative design to simplify the nominal/standard bunching system—replace the PB and B with the Hybrid Buncher (HB), which is a combined structure of the PB and the buncher. By using the bunching system with HB, beam dynamics studies show that similar beam performance can be obtained at the KIPT linac exit with a little bit lower construction cost.

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BUNCHING SYSTEM

Figure 1 shows the nominal/standard bunching system applied in KIPT linac and the alternative design we proposed to replace the PB and buncher by the HB.

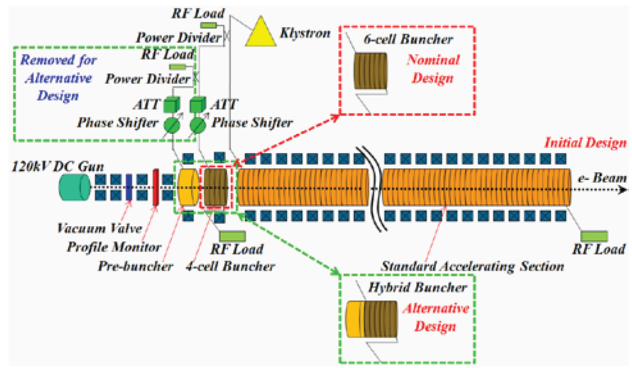

Figure 1: Bunching system.

It can be clearly seen from Fig. 1 that the bunching system with the HB has several advantages.

—More compact than a split system, allows scaling to higher frequency for a table-top system in the industrial applications.

—Much simpler high power RF system. Some waveguide section, attenuator, phase shifter, RF load can be avoided to lower the total construction cost.

—More flexible in the whole system installation and tuning, less parameters need to be adjusted and optimized.

—Completely removal of the impedance matching problem during the PB design and fabrication process, therefore the RF reflected power in real operation.

However, the bunching system with the HB also has disadvantages.

—Slight degradation of the beam performance.

—Demands relatively accurate calculation of the longitudinal distance between the SW and TW parts, which is based on the gun emitted beam energy.

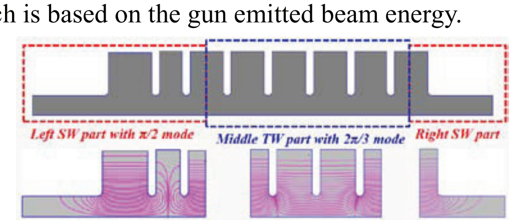

Figure 2: Initial 2D design of the HB by SUPERFISH.

INITIAL 2D DESIGN OF THE HB

To be comparable with the standard/split bunching system and check the feasibility of the bunching system with the HB in the KIPT linac, the TW part of the HB was also designed to have 6 cells. To accommodate RF field data to PARMELA [3], the initial 2D design (shown in Fig. 2) of the SW and TW parts were performed separately by setting appropriate boundary conditions in SUPERFISH [4]. The SW part operates at $\pi/2$ mode, while TW part at $2\pi/3$. Fig. 3 shows the electric field introduced into PARMELA for beam dynamics studies. After several iterations between RF design and dynamics simulation, the 2D design of the HB can be finalized.

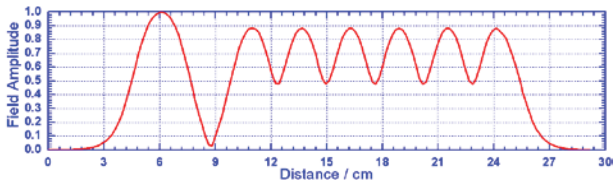

Figure 3: Electric field for dynamics studies.

BEAM DYNAMICS SIMULATION

To satisfy the energy spread requirement (<±4% p-to-p) at the 100 MeV / 100 kW linac exit [5], the bunching system with the HB should be able to produce similar energy spectrum as the nominal design, which is appropriate for the downstream collimation process. 600 mA beam (70% efficiency) should be able to be obtained after collimation (at the chicane system exit). Based on the above considerations, the bunching system with HB is optimized with the RF field data obtained from the 2D RF design. Fig. 4 shows the beam phase and energy spectrums at the bunching system exit, the corresponding spectrums for the nominal case are also shown for comparison. The HB bunching system has relatively lower transportation efficiency, while the bunch length of the main bunch part is relatively shorter.

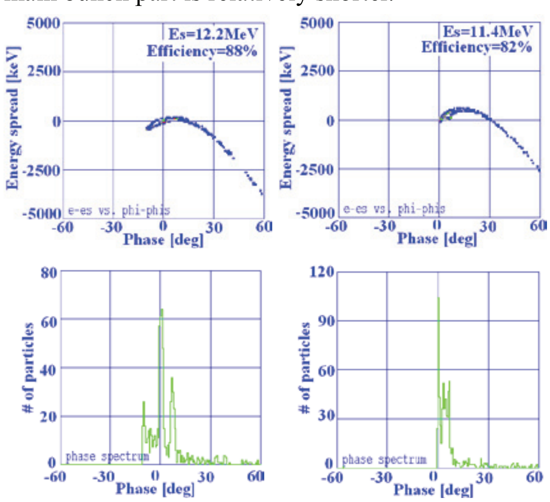

Figure 4: Spectrums at the bunching system exit (left for nominal bunching system; right for HB bunching system).

Figures 5 and 6 show the beam spectrums at the exits of the chicane system and the linac. Both the nominal and the HB bunching systems can satisfy the transportation efficiency requirement from the electron gun to the linac exit. However, the HB bunching system produces relatively bigger absolute energy spread at the linac exit. Fig. 7 shows the emittance evolution along the linac. By using the HB bunching system, the emittance at the linac exit is ~37% bigger, which is caused by the bunching process and can be reduced by further optimization of the Hybrid Buncher geometry.

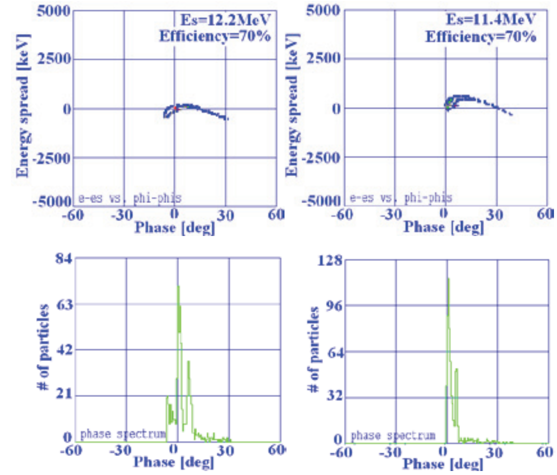

Figure 5: Spectrums at the chicane system exit (left for nominal bunching system; right for HB bunching system).

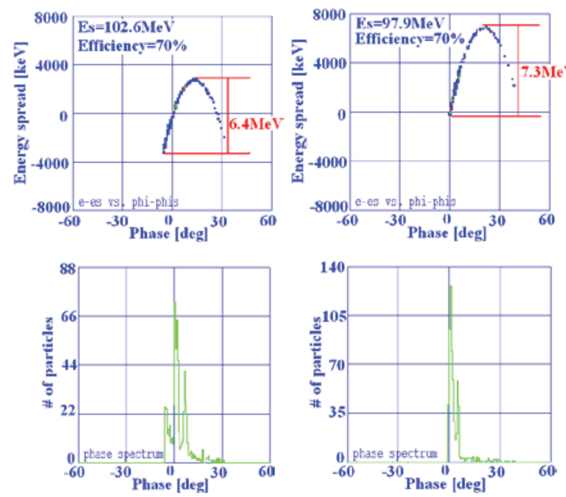

Figure 6: Spectrums at the linac exit (left for nominal bunching system; right for HB bunching system).

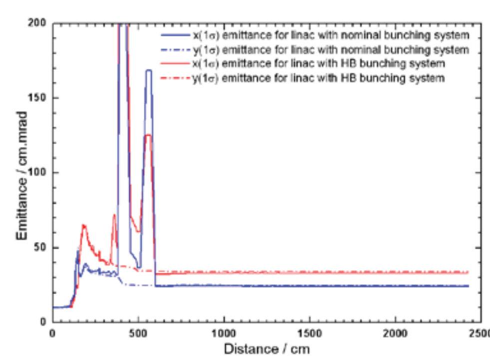

Figure 7: Emittance evolution along the linac.

3D DESIGN OF THE HB

The 2D RF design of the Hybrid Buncher is the starting point of the 3D design. Similarly, the SW and TW parts of the HB are designed separately. Fig. 8 shows the 3D model of the HB, Table 1 lists the main dimensions.

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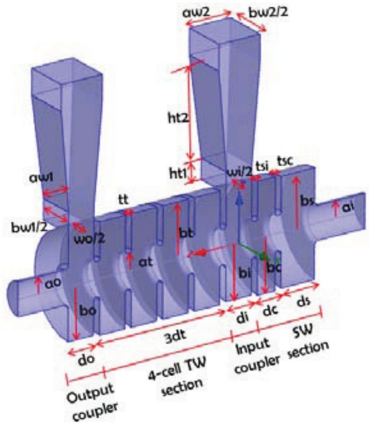

Figure 8: 3D model of the Hybrid Buncher.

Table 1: Main Dimensions of the Hybrid Buncher

Parameter	Value [mm]	Parameter	Value [mm]
ds	32.803	tsc, tsi, tt	5
dc	19.682	wi, wo	30.08
di, dt, do	26.242	ht1	15.9
ai, at, ao	13.11	ht2	76.2
bs	41.556	aw1	21.242
bc	42.442	bw1	61.087
bi, bo	41.045	aw2	34.163
bt	42.195	bw2	72.263

Conceptually, the SW section can be further divided into two parts: pre-bunching cavity and coupling cavity. The former is used for beam velocity modulation, while the latter as a beam drift. Both operate at $\pi/2$ mode. Length of each cavity is based on the 2D design and decided by the dynamics requirement. Based on the electron gun high voltage, the length of the coupling cavity in the SW section can be roughly calculated initially as the RF design baseline. Appropriate coupling cavity length is needed to place the beam at the positive slope of the RF field in the TW section to produce velocity bunching. The coupler matching of the TW section is based on the matching procedure for the $2\pi/3$ structure proposed by Dr. R. L. Kyhl and confirmed with the field transmission method. Attachment of the SW section with the TW section will increase the resonate frequency of RF input coupler cavity a little bit; therefore a modest bigger cavity size is needed.

Figure 9 shows the S11 at the RF input coupler port. Fig. 10 shows the phase and amplitude of the electric field along the axis of the Hybrid Buncher. To excite the RF field required by beam dynamics, the total needed RF power is ~0.7 MW. Only ~3% of the RF power goes to the SW section, thus both the RF phase and the field amplitude in the TW part are not very sensitive to the resonate frequency of the SW section, which is different from the hybrid photo-injector [2]. <0.5° phase change is found when the SW section has an off-resonance of 100 kHz. For temperature control of ±0.1 °C (±5 kHz off-resonance), the corresponding phase variation caused by the frequency off-resonance of the SW section is ~±0.025°, which can be ignored.

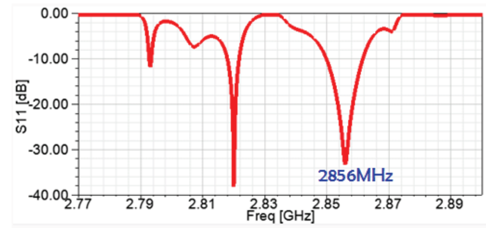

Figure 9: S11 at the RF input coupler port.

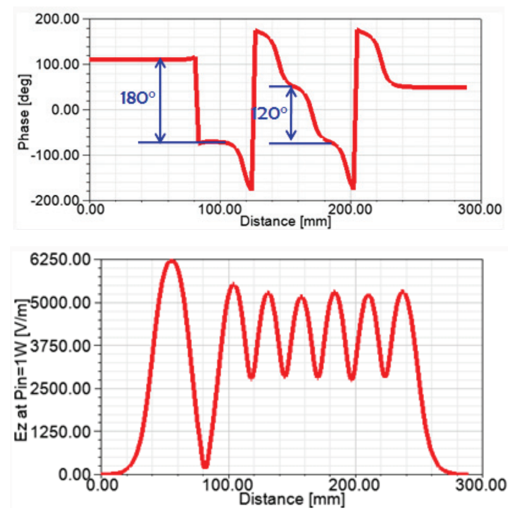

Figure 10: Phase (upper) and amplitude (lower) distribution along the axis of the Hybrid Buncher.

SUMMARY

To simplify the standard bunching system with slightly degraded beam performance and relatively lower construction cost, a bunching system with Hybrid Buncher used to replace the PB and buncher was designed, which can still satisfy the linac design requirement. For the gun high voltage quite different from 120 kV, the Hybrid Buncher needs to be redesigned. Besides the integration of the PB and B, the standard accelerating section can also be integrated with the HB together, which can further simplify the system and lower the cost.

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