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STUDIES ON THE S-BAND BUNCHING SYSTEM WITH THE HYBRID ACCELERATING STRUCTURE*

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Abstract

A standard bunching system is usually composed of a SW PB, a TW B and a standard accelerating structure. In the industrial area, the bunching system is usually simplified by eliminating the PB and integrating the B and the standard accelerating structure together to form a β-varied accelerating structure. The bunching efficiency for this kind of simplified system is lower than that for the standard one. The HB has been proved to be an innovative attempt to reduce the cost but preserve the beam quality as much as possible. Here, the HAS is proposed by integrating the PB, the B and the standard accelerating structure together to exclusively simplify the standard bunching system. Compared to the standard bunching system, the one with the HAS is more compact, and the cost is lowered to the largest extent without fairly degrading the beam performance. The proposed HAS can be widely applied in the industrial area.

INTRODUCTION

Generally, a standard bunching system is composed of a standing wave (SW) pre-buncher (PB), a travelling wave (TW) buncher (B) and a standard accelerating structure; all of them operate at the same radio frequency (RF) and are powered by one single klystron. However, for various reasons and different applications, the bunching system can be complicated or simplified. The complicated bunching system is always happened in the scientific area, and it is usually accompanied with better beam performance and higher construction cost. One typical example is the BEPCII sub-harmonic bunching system. Two sub-harmonic bunchers (SHB) were used to replace the PB [1]. In the industrial area, the usual way to simplify the bunching system and lower the cost is to eliminate the PB and integrate the B and the standard accelerating structure together to form a β-varied accelerating structure. However, the bunching efficiency will be lowered.

The hybrid buncher (HB) has been proved to be an innovative attempt to reduce the bunching system construction cost [2-4], and it is a combined structure of the PB and the B. Using the HB to replace the PB and B can simplify the bunching system to certain extent but not exclusively, it has been proved that the beam performance can be preserved as much as possible [4]. In this scenario, further simplification of the standard bunching system by integrating the PB, the B and the standard structure to form a hybrid accelerating structure (HAS) is proposed. It is worth to note that this paper focuses on the simplification studies of the standard bunching system operating at one single S-band frequency (2856 MHz). The bunching system with the β-varied structure was studied first, and then that with the HAS was investigated.

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BUNCHING SYSTEM LAYOUTS

Figure 1 shows the layouts of the standard bunching system applied in the linac of the NSC KIPT (National Science Center, Kharkov Institute of Physics and Technology, Ukraine) [5], the bunching system with the β-varied structure and that with the HAS. For both the simplified bunching systems, although the total linac length for S-band can only be shortened by several to twenty centimeters, but all the RF devices connected with the PB and B can be completely removed, this is more exclusive than the one with the HB [4]. Simplifying the bunching system with the HAS can lower the construction cost, facilitate the mechanical design and the tunnel installation, and less parameters need to be adjusted in the beam tuning process, while relatively accurate HAS design is needed, which depends on the gun emitted beam energy.

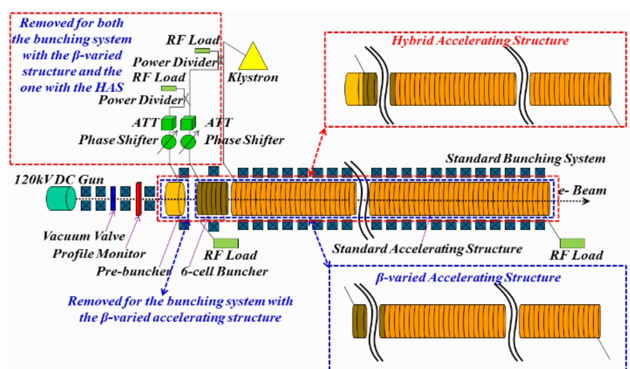

Figure 1: The bunching system layouts.

To easily compare the beam performance, the bunching system with the HAS was introduced into the KIPT linac [5] to replace the standard one. EGUN [6] and PARMELA [7] were used for the beam dynamics study. The RF power fed into the bunching system was all fixed to be 14.4 MW. The solenoid field distribution along the bunching system and the parameter setup for the chicane system were also adjusted to get the best beam quality at both the bunching system and the linac exits. At the bunching system exit, the higher the efficiency the better, and the energy spectrum should also be appropriate for the collimation process realized by a chicane system with a collimator deployed [8]. For the collimated beam, the RF phase for each accelerating structure downstream the chicane was optimized to minimize the energy spread at the linac end. At the linac exit, the more the particles within ±4% peak-to-peak (p-to-p) energy spread the better. This is demanded by the energy

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spread acceptance of the 90° beam transport line from the linac end to the neutron target [8].

BEAM DYNAMICS WITH THE BETA VARIED STRUCTURE

5 variants of the β-varied structure were studied. For each variant, the phase velocities of the first 8 cells are listed in Table 1. Besides, each β-varied structure still has 36 regular cells with β=1. The beam dynamics results are listed in Table 2. The efficiency at the linac exit is relative to the gun emitted beam current.

Table 1: The β Values for the First Few Cells of the β-varied Accelerating Structure

Cell #	Variant				
	1	2	3	4	5
1	0.88	0.75	0.75	0.75	0.75
2	0.92	0.88	0.75	0.75	0.75
3	0.95	0.92	0.88	0.75	0.75
4	1	0.95	0.92	0.88	0.75
5	1	1	0.95	0.92	0.88
6	1	1	1	0.95	0.92
7	1	1	1	1	0.95
8	1	1	1	1	1

Table 2: The Beam Dynamics Results for the Bunching System with the β-varied Accelerating Structure

Variant	The linac exit		
	Efficiency / %	E_{ave} / MeV	δE / MeV
1	26.3	98.8	±4.0
2	40.6	100.7	±3.9
3	48.1	101.5	±4.0
4	70.4	95.0	±10.1
5	73.1	83.4	±20.8

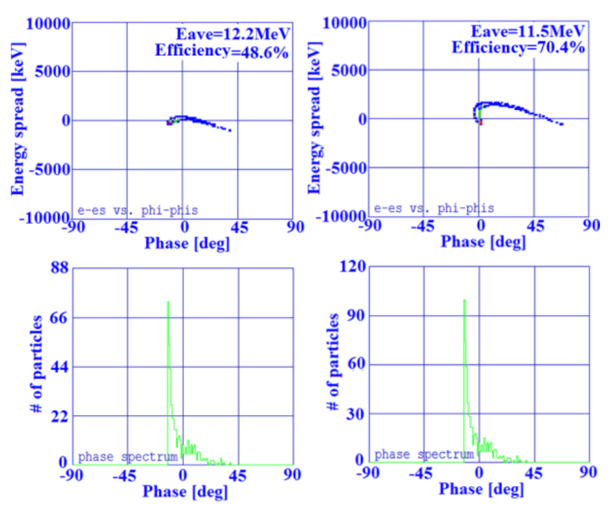

Figure 2: The spectrums at the chicane system exit (left for the variant 3; right for the variant 4).

After carefully analysing the results, one can get the following conclusions: a) By putting the p-to-p energy spread limit at the linac end to be ±4%, the variant 3 is the best, however the efficiency at the lianc exit is ~20% lower than the demanded ~70% [5]; b) Concerning the transportation efficiency, the variant 4 and 5 can meet the ~70% design goal, while the p-to-p energy spread is fairly bigger than ±4%, this will result in a severe beam loss along the 90° beam transport line located at the linac end.

Figure 2 shows the beam spectrums at the chicane system exit for the variants 3 and 4. The more the cells with β<1 introduced into the β-varied accelerating structure, the longer the bunch length and the bigger the energy spread of the collimated electron beam, which is the main reason of the bigger p-to-p energy spread at the linac exit.

For the bunching system with the variant 3, if the bunching efficiency at the bunching system exit can be increased by ~20% but not increasing the bunch length of the collimated electron beam, the design requirements for both the transportation efficiency and the p-to-p energy spread at the linac exit can be met, this is also true for the bunching system with the variant 4 if the bunch length of the collimated beam can be shortened to a certain level similar to that of the variant 3. All these problems can be solved by integrating the PB with the β-varied structure together to form the HAS. The β-varied structure is a pure TW structure, in which only TW RF field exists. While for the HAS, both the SW and TW RF fields exit, it combines all the functions of the PB, the B and the standard accelerating structure. The β-varied structures with the variant 3 and 4 are the most promising candidates for the TW section design of the HAS.

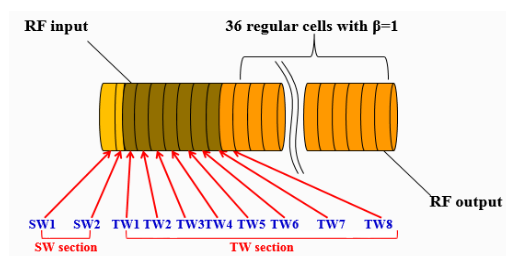

Figure 3: The schematic layout of the HAS.

BEAM DYNAMICS FOR THE HAS

Figure 3 shows the schematic layout of the HAS. The SW1 and SW2 are two cells operating at the SW $\pi/2$ mode, while the cells from TW1 to TW8 are eight cells operating at the TW $2\pi/3$ mode. By a large amount of beam dynamics simulations, it was found that the variant 4 listed in Table 2 is the best candidate for the TW section design of the HAS, the corresponding β values for the SW1, SW2 are 0.94 and 0.56 respectively. The SW section of the HAS is generally the same as that of the HB [3, 4], while the iris aperture between SW2 and TW1 was re-tuned to obtain an optimized field amplitude ratio of ~0.4 between the SW and the TW sections.

Figures 4 to 6 show the beam phase and energy spectrums at the exits of the bunching system, the chicane system and the linac. The spectrums for both the standard

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bunching system and the one with the HAS are listed. The bunching system with the HAS fulfils the transportation efficiency requirement of the electron linac. However, the bunching system with the HAS has relatively bigger absolute energy spread than the standard one.

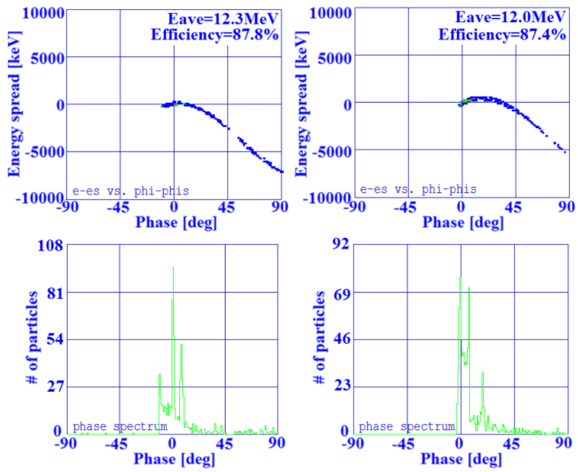

Figure 4: The spectrums at the bunching system exit (left for the standard one; right for the one with the HAS).

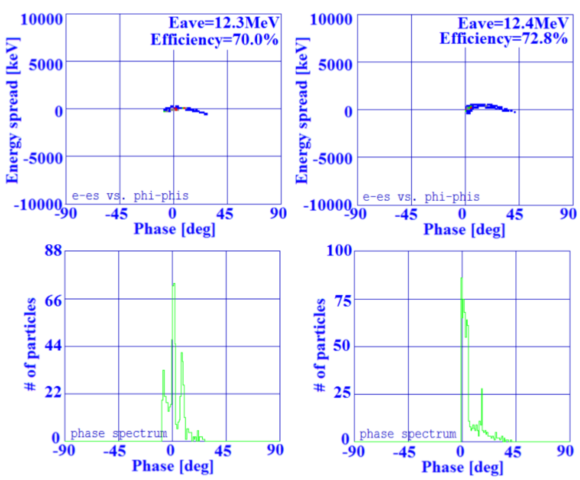

Figure 5: The spectrums at the chicane system exit (left for the standard one; right for the one with the HAS).

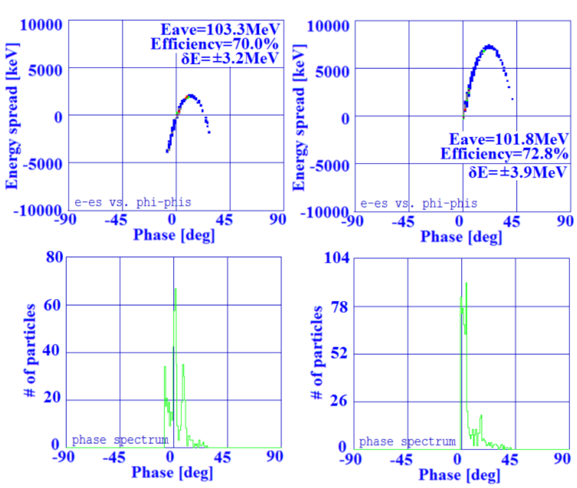

Figure 6: The spectrums at the linac exit (left for the standard one; right for the one with the HAS).

Figure 7 shows the transverse emittance evolution along the linac. For the bunching system with the HAS, the emittance at the linac exit is ~60% bigger, which is because of the relatively hasty bunching process. To obtain the best beam performance, the energy modulation in the SW section of the HAS is bigger than that in the PB of the standard bunching system. The drift space between the SW and TW sections for the HAS is also shorter than that between the PB and the B of the standard bunching system. For the bunching system with the HAS, it is unlikely to obtain the same emittance as the standard one; the drift length between the SW and TW sections cannot be too long for the RF power coupling reason, which means that a relatively bigger energy modulation by the SW section is always needed. At the linac exit, although the bunching system with the HAS has relatively bigger energy spread and emittance, it is still a better choice if the primary concern for the linac is the bunching or transportation efficiency, this is especially true for the industrial linacs.

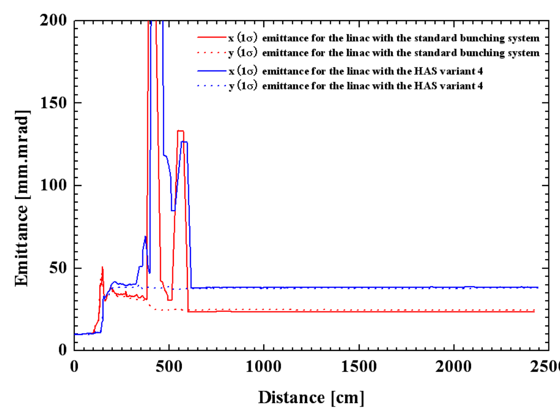

Figure 7: The emittance evolution along the linac.

SUMMARY

Compared to the standard bunching system, the one with the HAS is more compact, and the cost is lowered to the largest extent without fairly degrading the linac beam performance. In terms of the bunching efficiency and the construction cost, the proposed bunching system with the HAS can be widely applied in the industrial linacs, and can greatly increase the linac efficiency. Additionally, the compactness of the bunching system with the HAS also allows it to be easily scaled to a higher frequency, which is a better choice for the future table-top linac.

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