PROGRESS IN THE INJECTOR UPGRADE OF THE LINAC II AT DESY

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Abstract

A new injection system is under development for the LINAC II at DESY to improve the reliability of the machine and mitigate the radiological problem due to electron losses at energy of hundreds of MeV. It consists of a 100 kV triode DC gun, a 2.998 GHz pre-buncher, a novel 2.998 GHz hybrid buncher, and the dedicated beam transport and diagnostic elements. As the key components, the pre-buncher and the hybrid buncher realize a two-stage velocity bunching process including the ballistic bunching and the phase space rotation. Therefore, they produce a certain number of well-bunched 5 MeV micro-bunches from the input 2 ns-50 ns electron pulse for the downstream LINAC II. The overall upgrade plan, developments of the critical components, as well as the latest beam test results will be reported.

OVERALL INJECTOR UPGRADE

The layout of LINAC II at DESY and its injector upgrade are shown in Fig. 1 [1, 2]. LINAC II provides 450 MeV electrons for the light source PETRA III at the moment. Moreover, it has great potential to provide higher energy electron bunches (e.g. 800 MeV) for the Helmholtz distributed ARD facility SINBAD [3]. Within LINAC II, sections 1-3 are surrounded by solenoids with the maximum magnetic field of 0.08 T. The solenoid fields of sections 6 and 7 can reach 0.4 T in the case of positron operation. In addition, there are quadrupoles for the beam transport from the electron gun to PIA.

The new injector of LINAC II has been constructed and is being tested. Its main components are: an 100 kV DC triode gun that delivers 2-50 ns long electron pulses, a 2.998 GHz pre-buncher, a 2.998 GHz hybrid buncher consisting of both standing-wave (SW) and travelling-wave (TW) cells enclosed by a focusing solenoid, a dogleg that serves as an energy filter and delivers the electrons into the old gun beamline, 6 distributed quadrupoles, and a number of diagnostic instruments including 4 toroids, 6 beam position monitors and 4 fluorescent screens with 4 faraday cups inside. The old gun is kept as a reserved electron source. In a long term plan, it might be replaced with a photoinjector to produce ultra-short bunches. To make the coexistence of the two injectors possible, section 2 has been replaced by a beam transport line.

KEY COMPONENTS

For the injector, the critical problem is how to capture the non-relativistic electrons and bunch the ns long pulses into a certain number of micro bunches with high efficiency. Therefore, a two-stage Velocity Bunching

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(VB) strategy is employed. The first stage, i.e. the ballistic bunching is realized by the one-cell pre-buncher that operates at 90° ahead of the RF crest to introduce a primary velocity modulation. In the second stage, the phase space rotation [4] is used. It is an alternative to the magnetic compressor to provide high brightness ultra-short electron bunches that are required for FELs and some advanced accelerator concepts, such as the bunch-driven plasma wakefield accelerators. In our case, the hybrid buncher is used. The key issue is optimizing the injection phase and controlling the dephasing process that depends on the injection energy. If the injection energy is too low, the beam may transit across the RF crest, and then the de-bunching process occurs. To avoid this case, the one-cell SW section should have sufficient electric field to accelerate the incoming electrons rapidly.

In ASTRA [5] simulations, the wave phase of the hybrid buncher were optimized to make the output bunch length shortest. Here, the wave phase refers to the phase at the time $t = 0$ when the electrons start to be emitted at the cathode, denoted by Φ_0. Figure 2 shows the evolution of the bunch length σ_z versus the longitudinal position at different Φ_0. It can be seen that the optimal wave phase that gives the shortest bunch is -42°. When the bunch is compressed too fast, like in the case of $\Phi_0 = -60°$, the different longitudinal slices can crossover each other, as a result, the bunch length increases again after reaching the minimum value. If the bunch is compressed too slowly, like in the case of $\Phi_0 = -20°$, the bunching will be frozen before having reached the maximum compression due to the acceleration. In the case of $\Phi_0 = -42°$, the bunch is compressed to the minimum length and then the longitudinal waist is frozen, since the beam velocity has become close enough to the RF phase velocity.

Figure 3 shows variations of the momentum gain rate dP_z/dz and the relativistic velocity $\beta = v/c$ along with the longitudinal position for the synchronous electron in the centre of one micro bunch, from the entrance of the pre-buncher to the exit of the hybrid buncher. It can be seen that the synchronous electron has been neither accelerated nor decelerated after the pre-buncher. In contrast, in the hybrid buncher, it is accelerated rapidly by the SW cell from $\beta = 0.54$ to 0.75, and to 0.995 at the end of the TW section. The evolution of the momentum gain in the TW section implies that the bunch undergoes a dephasing process while being both accelerated and bunched over the first several cells, and then becomes approaching the crest of the wave mainly for accelerating. Such a combination is ideal to produce well-bunched relativistic electron bunches for the downstream LINAC II. Note that the field distribution in the hybrid buncher is not ideally flat in reality. However, the residual field unflatness after tuning is acceptable in the viewpoint of the beam dynamics performance, as illustrated in [6, 7].
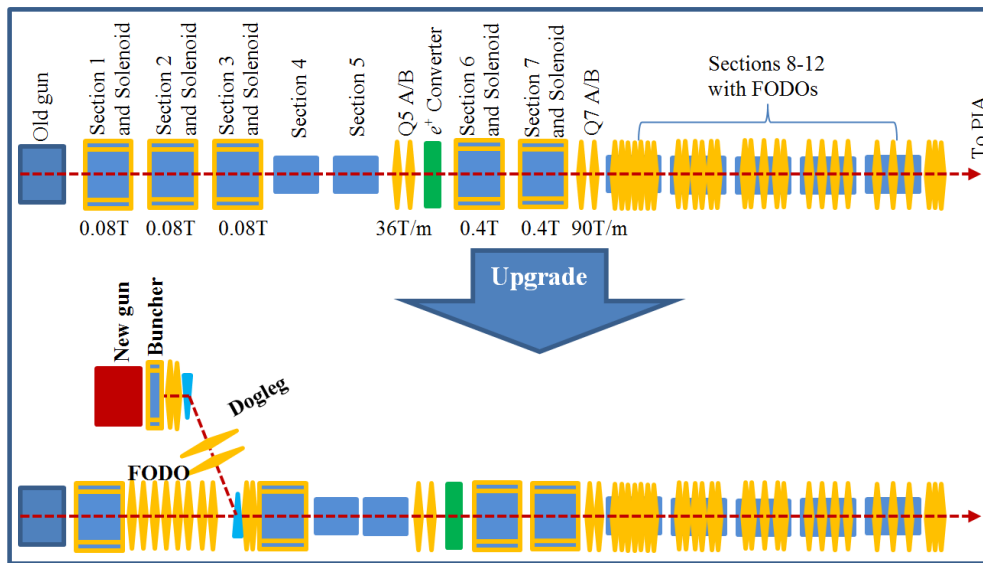
Figure 1: The layout of LINAC II at DESY and its injector upgrade.

In addition, Fig. 4 shows the structure of the buncher solenoid and the comparison between the measured on-axis magnetic field and the CST simulations. Under the same driving current of 1 A, the difference between the measured and simulated results is within 2%. Scale the peak field to the required focusing magnetic field 0.08T, the field profiles from measurement and simulation agree well with each other, while the corresponding magnet current needed is about 6.0 A.
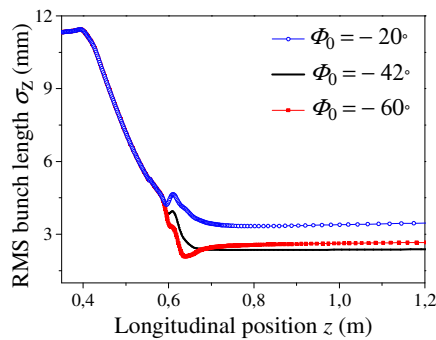

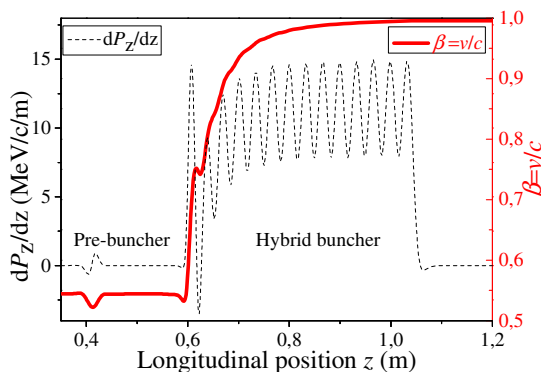Figure 2: Evolutions of σ_z versus z at different RF wave phases of the hybrid buncher at $t = 0$ (Φ_0).

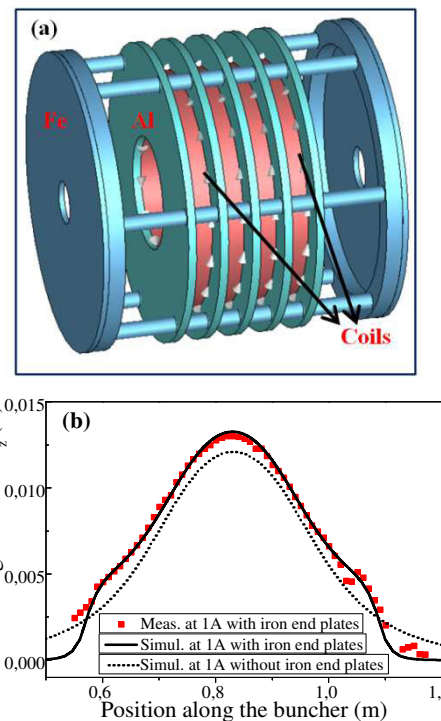Figure 3: dP_z/dz and β versus z, when $\Phi_0 = -42°$.

Figure 4: The structure of the solenoid surrounding the buncher (a), and the comparison of the solenoid fields between measurement and simulation (b). The two iron plates with small radius at the two ends aim to confine the magnetic field in between. The magnetic fields in the buncher cavity are hence enhanced by 10%.

SIMULATION AND MEASUREMENT

The start-to-end beam dynamics simulations and optimizations from the new gun cathode up to the end of section 5 of LINAC II have been performed. The key parameters that were optimized included the field amplitude of the pre-buncher, the injection phases of the

hybrid buncher and sections 3-5, the magnet strengths of the two dipoles in the dogleg, and the solenoid and quadrupole fields along the beam line.

Figure 5 plots the evolutions of the bunch momentum at several typical positions: after the pre-buncher, at the exit of the hybrid buncher, after the dogleg and at the end of section 5. The momentum modulation after the pre-buncher is optimal at ±10% relative to the central momentum. The injection time into the hybrid buncher is optimal to make the bunch length shortest at the exit. The accelerations in sections 3-5 are all on crest to obtain the maximum output energy, which approaches 260 MeV at the end of section 5. Note that in section 3 the phase space rotation technique can be performed to compress the bunch further. The energy acceptance in between the two dipoles is ±190 keV, so as to cut the low-energy tailing particles. As a result, the majority of the electron losses occur at low energy on the apertures of the hybrid buncher and the dogleg, especially at the entrance of the buncher where the aperture radius is much smaller than other places for particle scrape. Electron loss at energy higher than 10 MeV is extensively reduced, and the components activation is thus mitigated.

Figure 6 is the merging beamline from the new gun to the former beamline of the old gun. The beam test shows that the transmission efficiency between the two dipoles is around 70% when the beam current is several hundred mA. The accumulated number of electrons in PIA reaches 10^{10} from one macro bunch, which is as good as the previous value when the old gun was used.
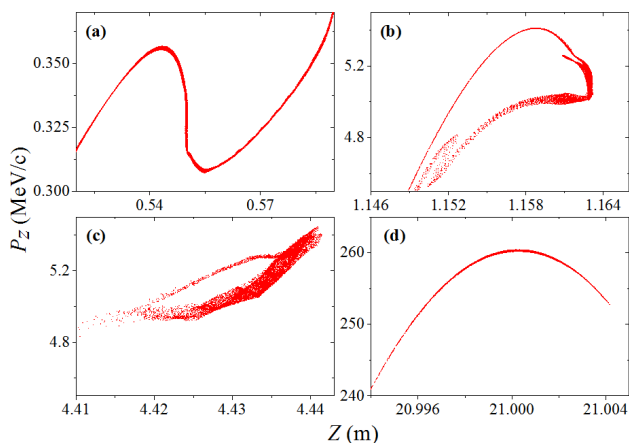

Figure 5: Evolutions of the beam momentum from the new injector to LINAC II: (a) after the pre-buncher, (b) at the exit of the hybrid buncher, (c) after the dogleg and (d) at the end of section 5.

SUMMARY

The research and development of the new injector of LINAC II at DESY have been discussed. By using the two-stage VB strategy realized through the combination of the 2.998 GHz pre-buncher and the hybrid buncher, the non-relativistic electron beam from the DC gun can be bunched with high transmission efficiency. The 5 MeV

bunches from the hybrid buncher are collimated by the dogleg consisting of two dipoles. The overall beam dynamics simulation shows that the majority electron loss occurs at energy below 10 MeV. Even though the unflatness of the buncher field is visible after tuning, its beam dynamics performance is still satisfying. The new injector is able to improve the reliability of LINAC II and solve the radiological problem due to electron loss at high energy. The new injector and the reserved old gun beamline have been commissioned preliminarily. Both guns can be used to provide electrons for PIA and then PETRA III at the moment.
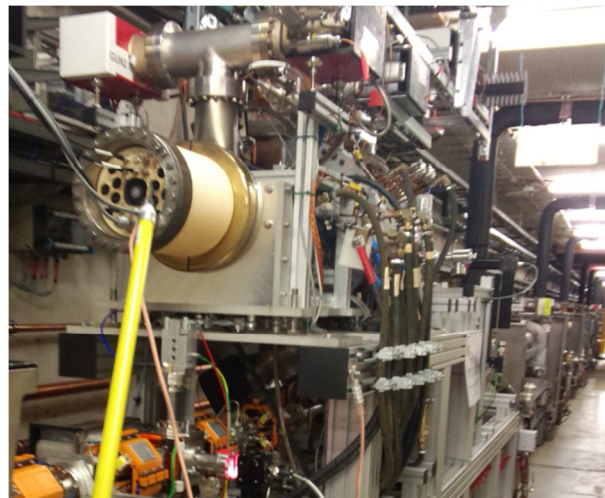

Figure 6: The new gun and the following beamline.

ACKNOWLEDGMENT

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