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BEAM DYNAMICS CALCULATION OF A NEW INJECTION SYSTEM FOR LINAC II

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Abstract

The Linac II at DESY (Deutsches Elektronen Synchrotron) is an electron/positron linear accelerator with a 400 MeV primary electron linac, an 800 MW positron converter, and a 450 MeV secondary electron/positron linac. For reliability two injection systems can be switched, a 150 kV bombarder diode gun dating from 1969 and a 100 kV triode gun commissioned in 2014. The older bombarder gun shall be replaced with a triode gun optimized for injection into the synchrotron radiation facility PETRA III. In this paper the parameters of the existing injectors and the design considerations for the new injector are presented. The preliminary beam dynamics calculation of the new injection system will be performed; the future plan of the replacement will be discussed.

INTRODUCTION

PETRA III (Positron Elektron Tandem Ring Anlage) is presently the most brilliant storage ring in the world. It provides high brilliant X-ray to users for cutting-edge experiments. The main part of the injector complex for PETRA III is Linac II, which accelerates electrons to 450 MeV and injects them into the accumulator PIA and then the synchrotron DESY II. DESY II continues accelerating electrons to 6 GeV and the high quality electron beam is finally injected to PETRA III. The light source experiments require a high reliability of the storage ring. Therefore, it is of great interest to reduce the likelihood of the technical failure and to shorten the time for general maintenance and potential replacement of fragile components. As the first part of the accelerator chain, it is important to keep the safe operation of Linac II.

Since 1969, a bombarder gun has been served as the electron generator of the injector complex. it can generate electrons and accelerate them to 150 keV with a pulse length of 30 μs at a repetition rate of 50 Hz and a peak current of 6 A. After the gun, a high-voltage chopper cuts the pulse length to 2-30 ns. A 2.998 GHz prebuncher focuses the electrons longitudinally and accommodates them into Linac II. The bombarder gun is operated in an oil bath for isolation and heat extraction purposes. The oil is separated from the beam vacuum only by a high-voltage ceramic isolator. Any rupture of the ceramic would lead to severe damage to the Linac and a consequence of a long downtime. Besides, the cathode preparation of the bombarder gun is not trivial.

To improve the maintainability of the system and to reduce operational risks, since 2014, a triode gun and a hybrid buncher at 2.998 GHz have been introduced into the injection system. The triode gun accelerates electrons to 100 kV with a pulse length of 2 ns. The bombarder gun was kept as a redundancy; a magnetic chicane is used to switch between the two gun operation. Figure 1 shows the overview of the current injection system of the Linac II and PIA [1].

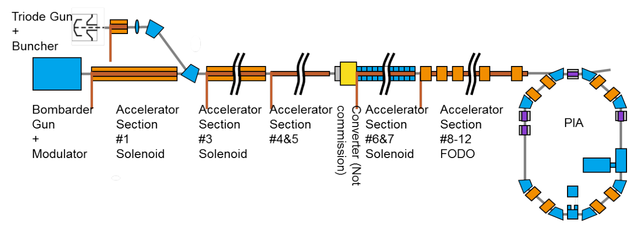

Figure 1: Overview of the current injection system of the Linac II and PIA.

To completely eliminate the risk of contaminating the Linac II, a plan to fully replace the bombarder gun is taken into account. A new injection system, which consists of a triode gun, a prebuncher and a buncher is a candidate. The injector and the preliminary beam dynamic calculation will be discussed in the following section.

In addition, the accumulator PIA, which was commissioned in 1979, has not been renewed for PETRA III. Any major problem in PIA would mean immediate shutdown of the entire following accelerator and the storage ring. Several critical components have already been identified with high risk. However, a complete abandonment of PIA is not advisable in the near future. Therefore, a bypass beam line for PIA is in high demand. The detailed bypass optics will be shown later.

NEW INJECTION SYSTEM

The S-Band Test Facility (SBTF) was originally designed in DESY for a 500 MeV Linear Collider. The injection system consisted of a triode gun, two subharmonic prebunchers, one at 125 MHz and the other at 500 MHz, and a travelling-wave (TW) buncher at 2.998 GHz. After the superconducting TESLA Test Facility, the SBTF was taken out and sent to Bonn to be used as the electron source for Elektronen-Stretcher-Anlage (ELSA) [2], where a few changes were made to accommodate the facility to the ELSA operation. After the finish of its commission in ELSA, the electron source and the bunching system were brought back to DESY.

Triode Gun and Bunching System

Figure 2(a) shows the drawing the electron gun. The original electron gun could generate electron beam with a maximum current of 6 A. To fit in the Linac I at ELSA, a modification was made to reduce the highest current to about 2 A. For the short pulse mode with a FWHM pulse length

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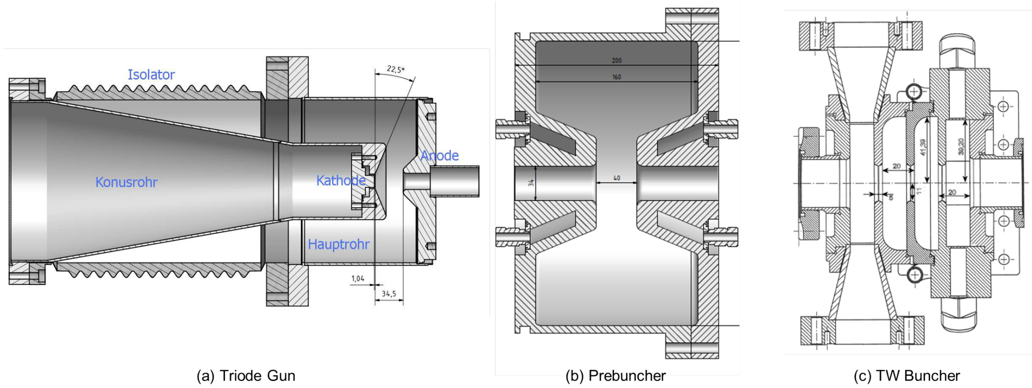

Figure 2: Drawing of the new injector system with (a) a triode gun, (b) a 125 MHz prebuncher and (c) a 2.998 GHz TW buncher. The dimension is in mm and is not scaled.

of 1 ns, the current is limited to 1.5 A. The cathode is a type YU-171 from EIMACS/CPI with an emitting cathode area of 1 cm^2. This allows a relatively low emittance of the beam generated by the source. The high voltage applied to cathode is 90-100 kV [2, 3].

Figure 2(b) shows the 500 MHz prebuncher with its "Nose-Cone"-Design. It is operated in a Standing-Wave (SW) mode. Figure 2(c) is the four-cell TW buncher.

Preliminary Longitudinal Beam Dynamics

The simulation of the electron field profile of the electron source and the bunching system were carried out by Poisson Superfish [4], and later were put into ASTRA (A Space Charge Tracking Algorithm) [5] for particle tracking. ASTRA is of great use to track charged particles at low energies when the space charge field is relative strong. In addition, by employing different commands, using ASTRA can lead to a preliminary optimized result considering the combination of parameters that influence the behavior of the particles. Those parameters include the phase and the field strength (the accelerating gradient) of the prebuncher and buncher, and the distance between those facilities. Figure 3 shows one scan result achieved by ASTRA, with the shortest bunch length occurring at $\phi = -33.10°$ of the prebuncher electric field. Choosing different beam quality, such as the

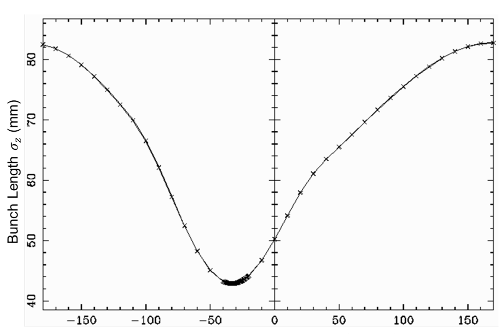

Figure 3: The electron bunch length after prebuncher versus the phase of the prebuncher electric field, calculated in ASTRA.

longitudinal emittance, the energy spread may lead to different optimized point; the final result is a compromise of all consideration.

Figure 4 shows the longitudinal distribution of the par-

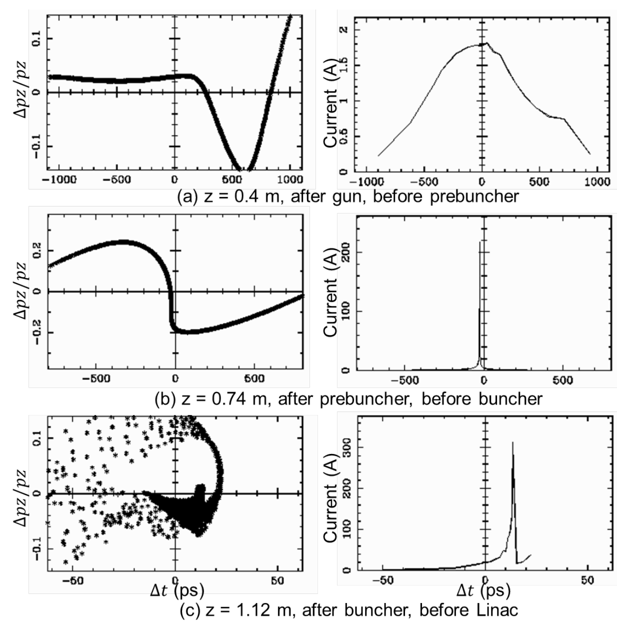

Figure 4: Longitudinal distribution of the electrons in different z position.

ticles calculated in ASTRA for three critical positions: (a) after the gun and before the prebuncher, (b) after the prebuncher and before the buncher, and (c) after the buncher before Linac II. The electrons forms a Gaussian beam shape from the electron gun with energies of ~ 90 keV (Fig. 4(a)). They start to bunch after the prebuncher. Figure 4(b) shows the bunched beam with the heading and trailing part not possible to be bunched. A chopper is considered to be installed to cut the electron bunch longitudinally. After cutting the unwanted electrons longitudinally after the buncher, Fig. 4(c) shows the electron bunch is short enough to be injected to the first section of Linac II.

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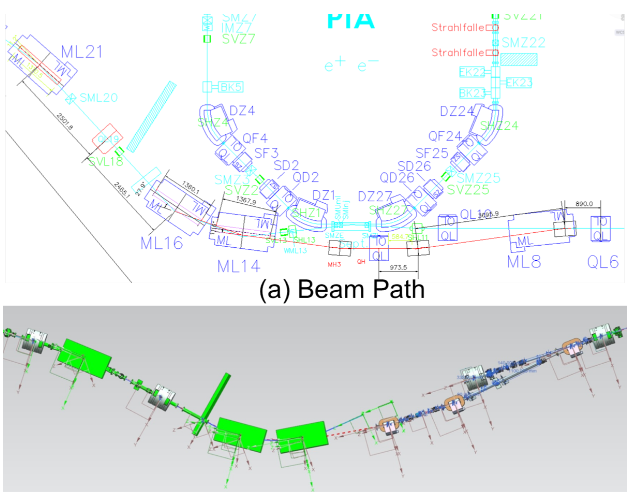
The detailed calculation, including the chopper and the transversal focusing of the electrons will be carried out sequently.

PIA BYPASS

Since the bypass of PIA will be served as an emergency operation in the near future in case of PIA shutdown, there are a few physical limits that have to be taken into accounts, including the geometry of the existing accelerator tunnel, the available magnets and power suppliers, the related interlock system, the interruption with the current beam path and so on. Besides, in order not to make major change of the existing optics following PIA to DESY, the beam quality deflected by the bypass optics should be matched to the current beam quality, after a few magnets away from the end of the bypass. The geometrical design was drafted by AutoCAD and a 3D modeling with details was generated by NX, which is shown in Fig. 5.



(a) Beam Path

(b) 3D Modeling

Figure 5: The drawing of the PIA bypass:(a) AutoCAD designed beam path, the bypass is shown in red, and (b) the NX 3D modeling of the bypass optics.

In order to match the beam quality after the bypass, the strength fo the quadrupoles along the bypass and the original beam line were optimized using MADx (Methodical Accelerator Design) [6]. Figure 6 shows the twiss parameter of the beam along the bypass. The twiss parameter at the end matches exactly with the existing beam.

CONCLUSION

The consistent behavior of the light source requires the safe operation of the injector complex. The upgrade of the injector complex, including a complete replacement of the old bombarder gun and a bypass beam line of PIA, is planned in the near future. Figure 7 shows the overview of the replacement of the bombarder gun with the triode gun. The preliminary longitudinal beam dynamics calculation of the new injecting system was carried out by ASTRA and will

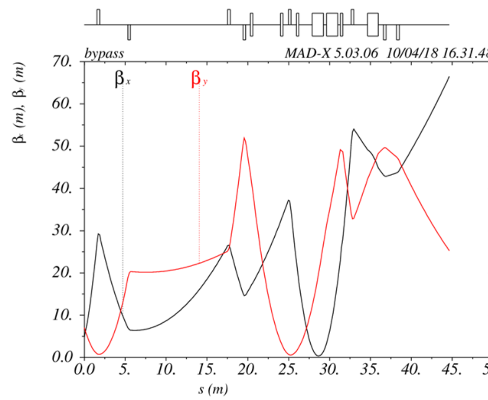


Figure 6: The twiss parameters along the PIA bypass calculated in MADx.

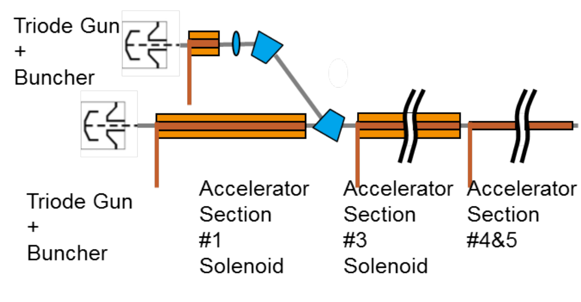


Figure 7: Overview of the replacement of the bombarder gun with the triode gun.

be continued with more details. For transversal focus of the electron beam, solenoid magnets will be implemented. The complete replacement is planned to take place in the next major maintenance time of PETRA III.

The design of the beam line of the PIA bypass has been completed. The bypass alone does not produce better beam quality. However it provides an alternative injection from Linac II to DESY in case of a sudden downtime of PIA. The optic components, as well as the diagnostics are under preparation and are planned to be built by the end of this year.

In the future, with the combination of the new injector, the emergency operation could be promoted to a full operation with complete replacement of the bombarder gun and PIA.

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