CONSTRUCTION AND FIRST TESTS OF THE NEW INJECTION SYSTEM FOR THE LINAC II AT DESY

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Abstract

For the Linac II, which supplies the accelerator chain at DESY with electrons and positrons, a new injection system has been built. It is supposed to ensure reliable operation and to avoid the beam loss of about 60% at energies up to 400 MeV and the associated activation. The function of the injector components, the entire injection system and the acceleration in the linac sections were optimized in simulations. The main components are a 6 A/100 kV triode gun, buncher and a dispersive section for energy collimation. The output energy is 5 MeV and the beam pulse length is 5 ns to 50 ns. The new buncher structure is a hybrid of a standing wave and traveling wave structure and allows a compact design and good electron capture. Its main part is a traveling wave structure in $2\pi/3$ mode, to which one capture cell is coupled in π mode. One of two assembled structures has been tuned and completed a test rig in the linac tunnel. In this test system detailed analysis of its properties is in progress as well as minor corrections like alignment and improvements of reliability. The final installation is going to take place from September 2013. First experimental analysis compared to simulation results will be presented.

INTRODUCTION

The Linac II at DESY accelerates electrons to 400 MeV using five S-band traveling wave structures at 2.998 GHz. The 400 MeV electrons can be accelerated further or alternatively be used for positron production with a tungsten target at the electron-positron converter. The converter is followed by another linac which provides 450 MeV positrons or electrons for the Positron Intensity Accumulator (PIA). Besides accumulation PIA serves for damping and compression of the pulses. PIA ejects the beam to the DESY II synchrotron that supplies the storage ring PETRA III, which serves as a high brilliance hard X-ray light source [1]. Since beginning of the year it is operated with electrons instead of positrons for the first time. Since the Linac II has been built in 1969 and high reliability is demanded, some changes were realized during the last years, part of which is the injection system [2].

Linac II Gun and RF System

At the moment 4 µs electron pulses with up to 6 A beam current are generated by a 150 kV DC gun whose tungsten cathode is heated via electron bombardment from the rear side. For electrical and heat extraction purposes the gun is operated in an oil bath, which is separated from the beam vacuum only by a ceramic. An electrostatic chopper cuts out pulses of 2 ns to 30 ns length and a prebuncher engraves the 3 GHz time structure to the pulses. The 150 keV beam is injected directly into the first linac accelerator section. In the accelerator structures the electron bunches are accelerated with an average gradient of about 80 MV/structure. Therefor the RF stations are equipped with SLED cavities, which increase the RF pulse power from 20 MW to up to 90 MW and decreases the usable pulse length from 4 µs with rectangular pulse form to a few 100 ns and a pointed peak.

Disadvantages of the Presently Used Bombarder Gun Setup

The major difficulties of this design are that in the linac sections losses of about 60% occur at high energies on the way to the converter and cause activation. Except current monitors no diagnostics are installed there at present to identify possible reasons for the losses. Furthermore, there is the risk that the ceramic of the gun takes damage and oil gets inside the vacuum system, which would lead to high costs and long downtime. In addition, the cathode preparation for the existing gun is not trivial, so that an alternative for the future had to be found.

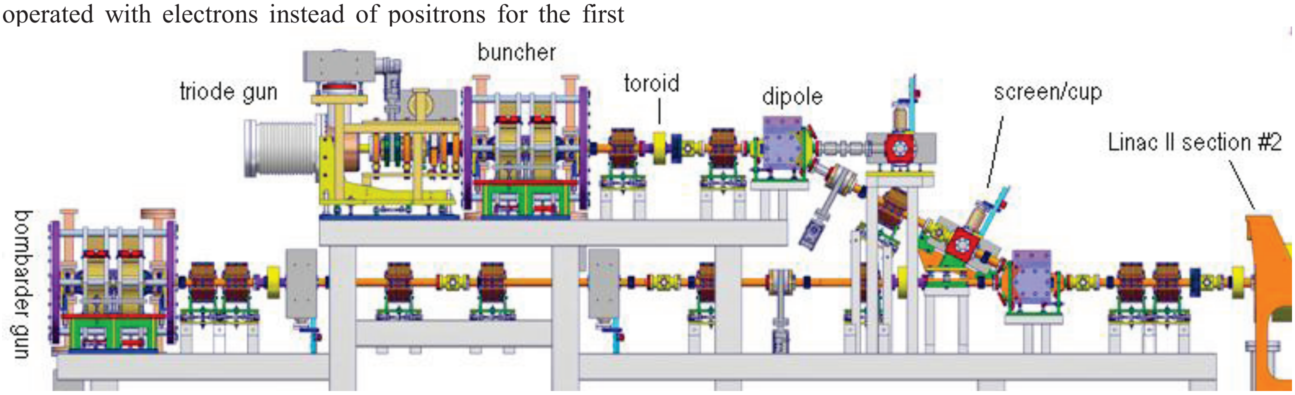

Figure 1: Design of the new injection system using a triode gun and the modified injection system beneath using the old bombarder gun. The system will be mounted in place of the currently first 5.2 m accelerator section.

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THE NEW INJECTION SYSTEM

One requirement of the new gun was to keep the option to operate PETRA III with positrons. So as a cathode an Eimac Y796 was chosen which delivers up to 6 A at 100 kV even though for the present operation with electrons very low current is sufficient. The gun delivers pulses with 5 ns to 50 ns length at a repetition rate of 50 Hz. Thus a chopper like in the old system is not required because of the triode construction. The electron pulses are formed into a 3 GHz structure by a prebuncher and focused by four solenoid magnets in front of the new hybrid buncher structure [2]. That has a $\beta = 0.5$ capture cell, which is operated in the π mode with a standing wave, while the other 13 cells are operated in $2\pi/3$ mode as a travelling wave structure. The travelling wave part corresponds to the design of the other linac accelerator structures. With a buncher gradient of 15 MV/m, the electrons are accelerated to 5 MeV. By means of a second coupling cell the remaining RF power is used to feed the following accelerator structure. That way no additional RF station is needed.

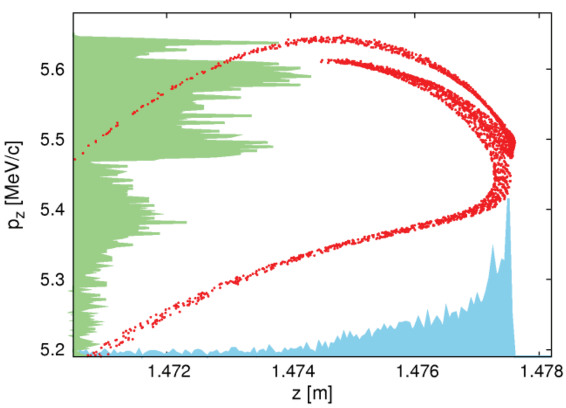

Figure 2: Astra computed distribution of a bunch in longitudinal phase space.

Downstream of the buncher a dispersive section directs the beam on the axis of the Linac II accelerator sections. This allows keeping the old gun as a backup system until the new gun has proven reliable. Only the first of at present five accelerator sections must be removed to make place for the bigger construction with another hybrid buncher structure, new optics and diagnostics. The dispersive section removes the fraction of beam which would be lost anyhow, but later at higher energies where it causes activation. Inside the dispersive section at around 5 MeV no activation can be expected. Electron distributions with an energy width of 250 keV can be transmitted through this chicane. Between buncher and first accelerator section five quadrupole magnets are placed for focusing.

Simulation

The improved electron capture in the hybrid buncher structure and the energy collimation in the dispersive section promise a lossless acceleration in the Linac II sections up to the converter. The layout of the new injection is shown in figure 1. The setup hast been optimized in simulations with Astra. The resulting distribution in longitudinal phase space behind the buncher structure is shown in figure 2.

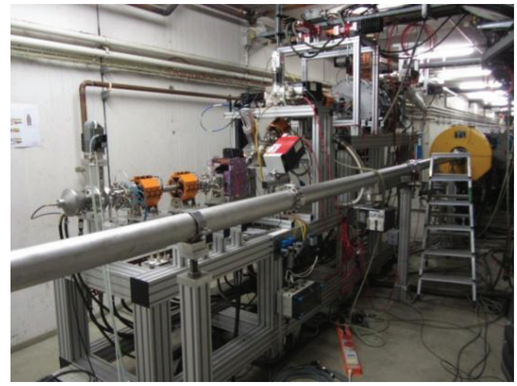

Figure 3: The test rig location in the Linac II tunnel. The linac beamline is visible in the foreground with the test rig behind. Beam direction is right to left.

MEASUREMENTS AT THE TEST RIG

Since January 2013 operation of the test system was possible for first measurements and by now detailed tests are performed. The current status of the test rig can be seen in figure 3.

Diagnostics

The diagnostics consists of four button BPMs, one toroid current monitor, two fluorescent screens with integrated Faraday cup and another Faraday cup at the end of the beamline. At present the entire diagnostics is located between the buncher and the following accelerator section. A wall current monitor in front of the buncher will be added soon. One BPM is located in front of the dispersive section, one in the dispersive section and two behind it. The fluorescent screens are built up straight ahead of the buncher, passing the first dipole of the chicane, and in the dispersive section respectively. The toroid is mounted between buncher and the dispersive section.

Transmission

For the tests peak current and pulse form were evaluated using the toroid and the three Faraday cups. After optimisations of the beam optics and bunching with the help of the BPMs and screens transmission through the whole system was achieved. However one reason for losses was misalignment of the buncher, the first two quadrupole magnets and the first dipole magnet. After corrections of aberrations bigger than ~1.5 mm beam current of 800 mA could be steered to the terminal Faraday cup. At the inductive current monitor up to 3.5 A with RF switched off and 2.3 A with an accelerating voltage of 6.6 MV in the buncher were measured. At the

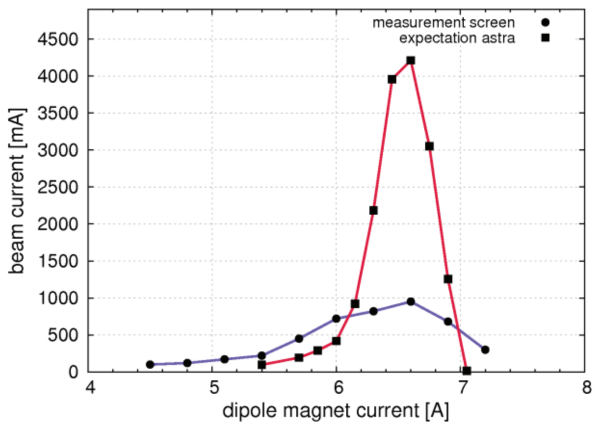

Figure 4: Measured peak beam current on the screen in the magnetic chicane compared to result from a scan using Astra.

screen in the magnetic chicane 0.9 A were reached. With the used gun settings an emission of 6 A at the cathode can be expected according to former tests. In the future this can verified with the additional wall current monitor. Achievment of better transmission is expected for further measurements.

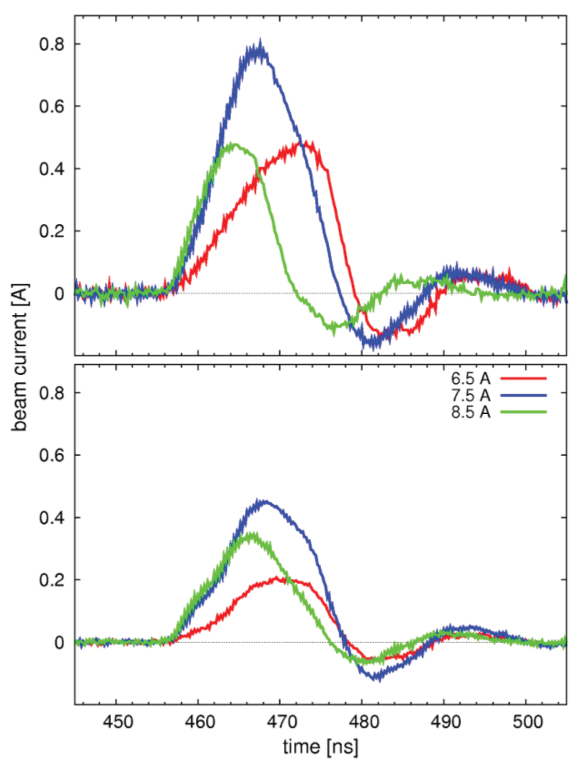

Figure 5: Beam pulses measured at cup in the magnetic chicane with 6.5/7.5/8.5 A dipole magnet current. The peak current at the toroid was 2.2 A (top) and 1.2 A (bottom) respectively.

Beamloading

Another challenge poses beamloading in the buncher structure at long pulse length and high peak current and hence high total pulse charge. Such high charges can be necessary when positron operation should be demanded again and thus high beam power at the converter is needed. Beamloading was investigated using the first dipole magnet with the screen behind as a spectrometer like setup. Resolution is however limited by the 1.5 cm diameter of the screen since no smaller aperture can be moved in the beamline. The effect induces a clear cutting in the long beam pulse caused by dispersion behind the first dipole magnet. Figure 4 shows the peak beam current versus dipole magnet current. The measured broad distribution with a pulse length of 20 ns is a result of beamloading. The expectation from simulations using Astra for a single bunch is narrower. In figure 5 the pulsforms measured at the screen are shown for different dipole magnet currents and for 2.2 A and 1.2 A peak current at the toroid respectively. On the left side with the higher beam current the cutting occurs earlier and sharper than for the low current pulse with less impact of beamloading. Partial compensation might be achievable in a simple way by timing of RF and beam pulse. If the beam pulse reaches the buncher while the rf power is on its steep rising edge, energy absorption of the beam pulse front can be compensated by the rising RF power. Testing of this method is still in progress.

CONCLUSION

The new injection system with a hybrid buncher structure for the Linac II at DESY will allow reliable operation of the Linac II and thus improve the availability of the following storage ring PETRA III. It has been completely installed in a test rig which allows stable operation and is ready for further experiments and adjustments where necessary. Final changes and the installation of the second beamline for the back-up system are planned for this summer. Therefor the system has to be removed from its location in the tunnel after all necessary measurements because there are too few access opportunities for major changes. After that the full system will be commissioned as new electron source for the Linac II in the shutdown from September 2013.

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