

# AN ELECTRON LINAC INJECTOR WITH A HYBRID BUNCHER STRUCTURE

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## Abstract

At present the Linac II at DESY consists of a 6A/150kV DC electron gun, a 400 MeV primary electron linac, an 800 MW positron converter, and a 450 MeV secondary electron/positron linac.

To improve the maintainability of the system and to reduce operational risks the original 150 kV diode gun will be replaced by a 100 kV triode. Together with the gun the whole injection system will be upgraded and optimized for minimal load on the converter target and primary linac.

The core of the new injector are a 5 MeV standing wave/travelling wave hybrid structure and a magnetic energy filter. Simulations show that with 6A DC current up to 3.7A can be bunched into 20° of the 2.998 GHz RF. This phase range is narrow enough to fit after on-crest acceleration into the energy acceptance of the following accumulator ring PIA.

## INTRODUCTION

At present the primary electron beam for the Linac II is produced by a 120 kV pulsed DC diode gun. Beam pulses of up to 6 A and 4 μs duration are produced. The cathode is made by a carborated tungsten plug, heated by a 3 kV, 1.2 kW bombarder. An electrostatic chopper cuts the pulse duration to 2 ns to 30 ns, depending on the operation conditions.

There are two main problems associated with this setup. The first problem arises from the fact that the cathode plugs are no longer commercially available. To continue using this kind of cathode, DESY would have had to build up its own infrastructure for their preparation. Second, the high voltage insulator of the cathode is immersed in oil. Although this has worked well for 40 years now, the cost would be immense in case it broke and oil contaminated the vacuum system.

Therefore it was decided to replace the gun by a type with a commercially available cathode. The EIMAC Y796 was chosen which is capable of delivering 6 A of beam current. The acceleration voltage is set to 100 kV. The chopper can be omitted because the Y796 is a triode.

The present injector delivers 150 kV beam directly into the first accelerator section. The new injector will contain a 5 MeV buncher section. The first cell is shorter to match to a lower beta. A magnetic chicane will serve as an energy filter to cut away the unbunched beam and will allow operation of two parallel guns.

## LINAC OVERVIEW

### Accelerator Sections

The linac sections are 5.2 m travelling wave S-band structures, operating at 2.998 GHz. They are constant gradient structures with an on-axis load. Therefore the last six of their 154 cells are coated with an absorbing material and add little to the total accelerating voltage. The fill-time of the structures is 720 ns. The original structures were replaced by a design made for the S-Band Linear Collider Test Facility [1].

All but one of the RF stations are equipped with SLED cavities for pulse compression, increasing the peak power from 20 MW to 90 MW. With this the structures achieve an average gradient of 18 MeV/m or 90 MV/structure. The klystron drive is provided by the RF station number 9, which therefore cannot use the SLED scheme. Phase and amplitude are adjusted via high power phase shifters and adjustable attenuators. The phase jump for the SLED is produced individually by PIN-diodes in the drive of each klystron. At approximately 400 MeV there is the converter target. The beam current at this point usually is 2 A. Six linac sections are available to bring the secondary beam energy to 450 MeV (figure 1).

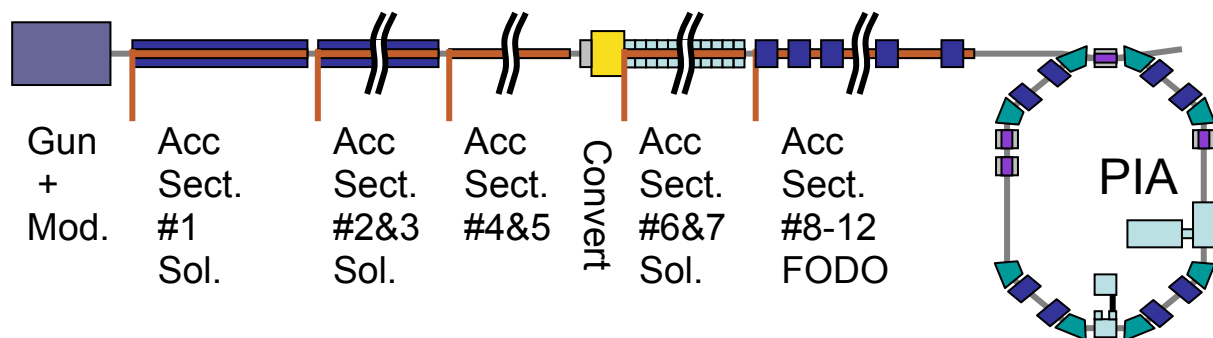


Figure 1: Schematic layout of the Linac II at DESY. The 6 A primary beam is produced in a 120 kV pulsed DC gun and directed onto a converter target at roughly 400 MeV. The secondary beam is accelerated to 450 MeV and injected into the Particle Intensity Accumulator (PIA).

## PIA

The electrons or positrons at 450 MeV are injected into the PIA (Particle Intensity Accumulator) ring. The revolution frequency in PIA is 10.4 MHz and so is the frequency of its RF system [2]. The beam is damped longitudinally with only the 10.4 MHz RF system to 1.5 ns (RMS) [3]. A second RF system at the 12<sup>th</sup> harmonic produces a bunch length of 400 ps (RMS). The damping time of the synchrotron oscillation is 12.9 ms, the damping time of the betatron oscillation is 23.6 ms. With 12 shots from the linac  $2 \cdot 10^{10}$  positrons can be accumulated routinely. This corresponds to an efficiency of 4% from beam on target to accumulated particles.

## THE NEW INJECTOR

For the design the following tasks were considered. The current of the old injector must at least be reached if not exceeded. Neglecting expected efficiency gains this calls for a DC current of 6 A. To reach this an EIMAC Y796 was chosen for the cathode.

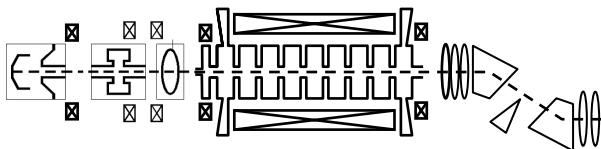


Figure 2: Schematic layout of the new injector. The DC beam is generated in a 100 kV, 6 A gun. The 3 GHz prebuncher and bunching section deliver bunched beam at 5 MeV. The chicane allows for energy filtering.

A DC voltage of 100 kV is foreseen. Beam pulses between 2 ns and 50 ns are formed by pulsing the grid.

A 2.998 GHz re-entrant cavity is used as a prebuncher. The RF power is tapped from the input of the buncher structure. The buncher structure is a 2.998 GHz travelling wave structure operating in the  $2\pi/3$ -mode. For better matching to the velocity of the incoming beam a capture cell is attached to the input of the structure. This cell is coupled in  $\pi$ -mode to the first cell of the buncher. Thus the buncher is a hybrid of standing wave and travelling wave. The beam is accelerated to approximately 5 MeV.

The connection to the linac is done through a magnetic dogleg chicane (see figure 2). This offers the possibility to operate a redundant injector and to setup energy filtering. In this way the bunches can be tailored to the acceptance of the downstream machines. Unbunched and off-energy electrons are stopped at low energy reducing activation of downstream accelerator components.

## THE BUNCHER STRUCTURE

The design of the buncher structure is based on that of the other accelerating structures in the linac. Several changes were made to adapt the structure to its special task. The number of conventional cells is reduced to 13. With an average gradient of 12.5 MV/m this corresponds to an energy gain of 5 MeV. Instead of an on-axis load the

buncher has a output coupler. The linac structures are of constant gradient type. The tapering of the cells is not applied, because the effect will be neglectable with 13 cells only. The output coupler is a copy of the input coupler. At one point of the structure a disk is inserted to allow brazing of the cups from both ends.

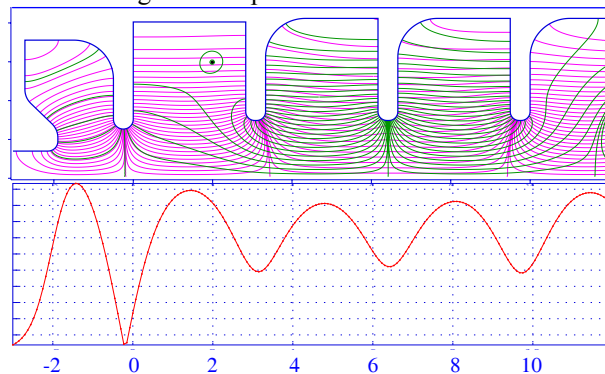


Figure 3: Cross section and field profile in the first cells of the buncher structure. The buncher is a travelling wave section with a capture cell coupled in  $\pi$ -mode (standing wave) to the first cell.

To achieve a better capture efficiency and gain more freedom in adjusting the longitudinal phase space, a first cell was added which is matched to an incoming particle velocity of  $\beta=0.5$ . For best flexibility in the design and to ease the adaption to the original structure it was decided to attach the cell upstream of the input coupler. It is coupled to the first cell in the  $\pi$ -mode, i.e. standing wave. The larger phase difference compared to the standard  $2\pi/3$  is a benefit for the velocity matching.

The beam pipe radius is reduced at the input to achieve a faster cut-off. To avoid a re-design of the input coupler the outer diameter of the capture-cell had to be reduced. This required a re-entrant cell design. The iris between the capture and input cells has a reduced diameter to account for the change in tuning. The cross section and field profile of the structure is shown in figure 2.

Operation of the short structure with an individual klystron would be relatively ineffective because the filling time is so short. Therefore the output power is fed into the subsequent acceleration structure. The phase between the structures is adjusted with a high power phase shifter in the vacuum waveguide.

The original SLED principle creates RF pulses with very high power at the beginning of the pulse which quickly drops towards the end. This is not advantageous in the first structure of the linac because then the lowest RF field is at its entrance. This can be alleviated by changing the phase modulation of the klystron pulse. Instead of one phase jump of  $180^\circ$  there is a smaller jump with subsequent phase slope. The SLED cavity has to be detuned to compensate for the phase slope. In this way an almost rectangular RF pulse can be achieved leading to a truly constant gradient along the structure [4]. This however requires an individual preamplifier for the corresponding klystron.

## BEAM DYNAMICS

The beam is produced at the cathode with pulse lengths between 2 ns and 50 ns but otherwise unmodulated. The 2.998 GHz of the linac RF system are first imprinted on the beam in the prebuncher cavity. The energy modulation is converted into a density modulation on the way to the buncher structure. Within the buncher the electrons are accelerated to approximately 5 MeV so that afterwards the bunching is basically frozen. For best capture efficiency the voltage of the prebuncher is adjusted to actually over-compress the bunches. This can be identified in figure 4 by the folding of the phase-space distribution.

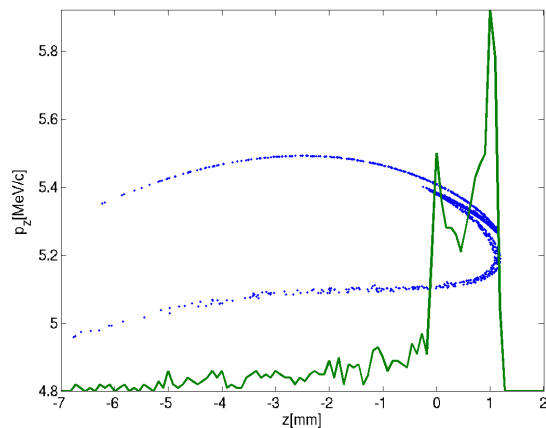


Figure 4: Longitudinal phase space distribution at the end of the injector and longitudinal charge density. The total displayed charge is 1.2 nC corresponding to 3.6 A.

The cathode has an area of 2 cm<sup>2</sup> to allow the emission of sufficient beam current. At an accelerating voltage of 100 kV the field on the surface is 1.75 MV/m and the peak field 3.2 MV/m. This is enough for the emission of 6 A at an emittance of 15 $\pi$  mm·mrad (figure 5).

The longitudinal over-compression causes a high charge density at the entrance of the buncher structure where the energy is still low. This results in a doubling of the emittance which is however easily tolerable for operation of the positron target. The present injector delivers approximately 200 $\pi$  mm·mrad. With less aggressive compression better emittance preservation is expected which might be useful for future applications.

Because the initial beam current is unmodulated, the bunching causes beam loss. Approximately 25% of the beam has to be considered unbunched. This beam is lost in the injector or at the latest in the energy collimator. At energies below 5 MeV this will not cause radiological activation of components. In the present setup 70% of the beam is lost along the first 400 MeV of the linac leading to radiation damage and activation along the beamline.

With the given setting of the compression very short bunches are produced. As can be seen in figure 4 up to 60% of the initial beam current are concentrated in 6° of the S-band RF. Although the conversion process produces

a large spread in the transverse and longitudinal moments, the temporal spread of the bunch is nearly preserved. Therefore the initial bunch length determines the amount of additional energy spread which is produced in the subsequent acceleration. It is therefore expected that a reduction of bunch length improves the conversion to accumulation efficiency [5].

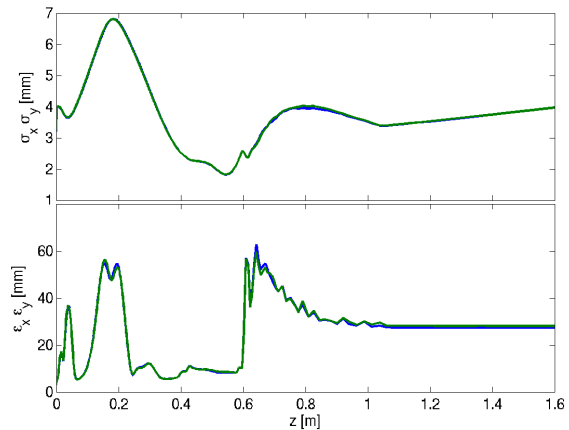


Figure 5: Beam size and emittance along the injector. The emittance calculation is affected by the RF and solenoid fields.

## SUMMARY

A new injection system is being built for the DESY Linac II. At comparable DC current it will deliver much more bunched current to the converter than the present setup. Further improvements are the expected prevention of beam losses at high energies along the primary linac and an expected improvement in conversion efficiency.

To avoid the need for additional RF stations a new buncher section is designed with a hybrid operation mode of standing wave and travelling wave.

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