A NEW HIGH CURRENT AND SINGLE BUNCH INJECTOR AT ELSA

Manuel Schedler, Philipp Hänisch, Wolfgang Hillert, Dennis Proft, Jens Zappai
ELSA, University of Bonn, Germany

Abstract

At the Electron Stretcher Facility ELSA of Bonn University, an increase of the maximum stored beam current from 20 mA to 200 mA is planned for the stretcher ring.

In order to keep the desired duty cycle of the post acceleration mode at about 80 % a new high current injector operating at 3 GHz has been built. It provides an electron beam with an energy of 20 MeV and a beam current of 800 mA in pulsed operation. A prebuncher, travelling wave buncher system and an energy compressing system are installed in order to enhance the beam acceptance of the linac and to reduce the energy spread in order to achieve an improved injection efficiency into the booster synchrotron.

For studying accelerators impedances and beam instabilities the linac is able to produce single bunches with a pulse current of 2 A which will be accumulated in the stretcher ring.

THE ELECTRON STRETCHER ACCELERATOR – ELSA

Future hadron physics experiments at the Electron Stretcher Facility ELSA require an increase of the accelerator's beam current by one order of magnitude. Electrons are produced at either Linac 1 using a thermal electron gun or at Linac 2 even providing a beam of polarized electrons. The adjacent booster synchrotron accelerates the electrons to an energy of typically 1.2 GeV, operating at mains frequency of 50 Hz. The stretcher ring accumulates several shots of the booster synchrotron and offers acceleration to a maximum energy of 3.2 GeV, applying a fast energy ramp of 6 GeV/s. On flattop energy, the electrons are slowly extracted over a few seconds to the hadron physics experiments using resonance extraction methods. Afterwards, the stretcher ring is prepared for the next injection process by ramping down the magnets [1]. An overview of the accelerator facility and the hadron physics experiments is given in Fig. 1.

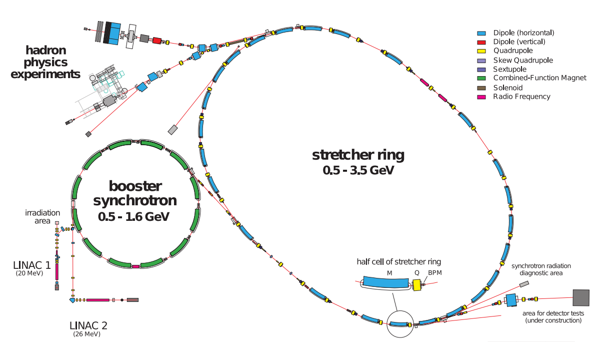

Figure 1: The Electron Stretcher Accelerator Facility ELSA.

To keep the duty cycle at reasonable values of about 80 % when operating with high intensities, the injection current has to be increased significantly. For this purpose, the Linac 1 is upgraded to high current mode. To achieve a maximum booster injection efficiency, a bunching section and energy compressing has been installed at Linac 1. In addition, it will provide a single bunch capable operation mode, which can be used for single bunch instability studies in the stretcher ring. To successfully accumulate electrons in a single bucket in the stretcher ring, a new FPGA based timing system has been developed.

MAIN OVERVIEW OF LINAC 1

A thermal electron gun is used to generate electrons with an energy of 90 keV, followed by a 500 MHz sub-harmonic prebuncher and a 3 GHz travelling wave buncher. The main linac structure accelerates the electrons to 20 MeV [2]. To reduce the energy spread and thereby enhance the booster injection efficiency which is mainly limited by it's energy acceptance, an energy compressing system has been setup behind the main linac structure.

The generated electron beam can either be filled into the booster synchrotron or can be used for material irradiation at the linac's test area.

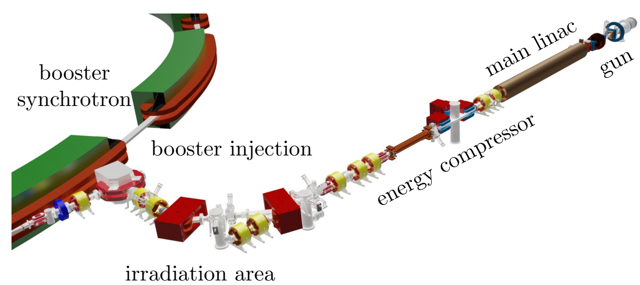

Figure 2: Overview of the new single bunch and high current injector Linac 1, the transfer line to the booster synchrotron, and the irradiation area.

THE ENERGY COMPRESSING SYSTEM

The energy spread of the electron beam produced by the main accelerating structure amounts to $\Delta p/p = 5 \cdot 10^{-2}$ whereas the energy acceptance of the adjacent booster synchrotron is about one order of magnitude smaller [3].

In order to optimize the injection efficiency into the booster synchrotron, the energy spread of the electron beam of Linac 1 has to be reduced by one order of magnitude. Even using the multi-stage bunching process of the injector, the energy spread has to be further reduced after acceleration in the main linac. This is achieved by adding an energy compressing system.

ISBN 978-3-95450-142-7

A dispersive debuncher section is used to rotate the phase space distribution of the electron beam in order to sort the electrons by their momentum, using three dipole magnets. The curvature of a single electron's trajectory in a dipole magnet can be described by

$$r(p) = \frac{p}{eB} \tag{1}$$

where r is the radius of the particle's orbit and B the magnetic field of the dipole magnet. Different momentums lead to different curvatures and thus to different path lengths. The resulting particle distribution contains a dependence of the particle's momentum on their longitudinal position. The adjacent accelerating structure is used to apply a longitudinally alternating electric field to the debunched beam in order to deaccelerate or re-accelerate electrons depending on their longitudinal position in the bunch. By choosing an appropriate RF phase for this acceleration, the energy spread can be reduced by about one order of magnitude. A scheme of the energy compressing is given in Fig. 3.

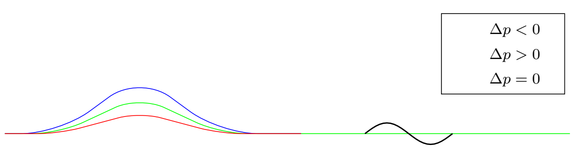

Figure 3: Scheme of the energy compressing system.

The accelerating structure of the energy compressing system is a normal conducting, 28 cell 3 GHz RF travelling wave structure, manufactured by Research Instruments GmbH.

The output power of the main klystron is splitted in order to drive travelling wave buncher, main linac and energy compressing structure. The RF amplitude and phase of both travelling wave buncher and energy compressing system can be changed relatively to the main linac using a hybrid based high power in-vacuum waveguide system in order to achieve a maximum bunching and energy compression effect.

A NEW HYBRID BASED WAVEGUIDE SYSTEM FOR LINAC 1

In order to drive the travelling wave buncher, the main linac, and the energy compressing accelerating structure, a pulsed 3 GHz klystron is used. A hybrid and phase shifter based high power WR284 waveguide system is used for power distribution to the three accelerating structures with individual and adjustable RF powers and phases. Fig. 4 shows the schematic of the new waveguide system.

The two output arms of the main klystron are combined using the 3 dB hybrid coupler H2. In order to couple the main part of the RF power to the main linac and a small part to the bunching and energy compressing structures, the hybrid H1 is used as a phase shifter by shorting it's two output ports, using position variable in-vacuum RF shorts, shown in Fig. 5. By varying the position of the shorts synchronously only the output phase of the hybrid with respect to the input one

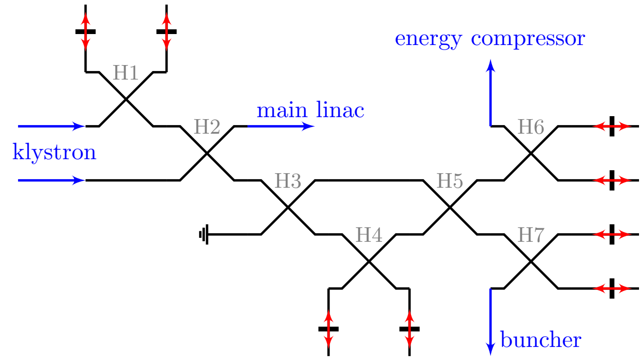

Figure 4: Schematic of the new waveguide system including 3 dB couplers and variable waveguide shorts.

is affected. The waveguide shorts base on a design of TU Dortmund [4] and have been modified to fulfill ultra high vacuum requirements.

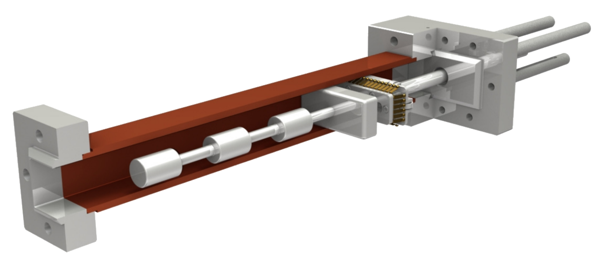

Figure 5: Variable in-vacuum high power waveguide short.

The voltages U_i of an outgoing wave at each of the four ports of a 3 dB-hybrid depend on incoming waves of amplitude U at ports 1 and 4 and can be described by the matrix formalism

$$\begin{pmatrix} U_1(t) \\ U_2(t) \\ U_3(t) \\ U_4(t) \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -\mathrm{i} & -1 & 0 \\ -\mathrm{i} & 0 & 0 & -1 \\ -1 & 0 & 0 & -\mathrm{i} \\ 0 & -1 & -\mathrm{i} & 0 \end{pmatrix} \cdot \begin{pmatrix} \frac{U}{\sqrt{2}} \mathrm{e}^{\mathrm{i}\omega t} \\ 0 \\ 0 \\ \frac{U}{\sqrt{2}} \mathrm{e}^{\mathrm{i}(\omega t + \varphi)} \end{pmatrix}, \tag{2}$$

One of the input waves is phase shifted by φ to adjust the output powers at ports 2 and 3 according to

$$P_2 \propto |U_2|^2 = \frac{U^2}{2} (1 + \sin(\varphi)) \tag{3}$$

$$P_3 \propto |U_3|^2 = \frac{U^2}{2} (1 - \sin(\varphi)) . \tag{4}$$

In the same way, a hybrid can be used as a splitter by driving a single input port, which is used in H3. To avoid damages from undesired reflected powers, the second input port of H3 has to be terminated using a water cooled RF load.

These schemes are used in hybrids H4 and H5 as well, splitting the remaining RF power for travelling wave buncher and energy compressing structure. The adjacent hybrids H6 and H7 are connected to the energy compressing structure and the travelling wave buncher and used as phase shifters for both paths, individually.

All the system has been designed to handle powers of up to 30 MW and allows full amplitude and phase control of the three output paths by varying the position of the waveguide shorts.

A SINGLE BUNCH INJECTION TIMING SYSTEM

To achieve a single bunch accumulation in the stretcher ring, a new bucket synchronous timing system is required. This has been realized using a fast Xilinx Spartan-6 FPGA based approach, supplying all the trigger signals required for electron pulse generation and booster injection and extraction. Fig. 6 shows the FPGA logic of the new injection timing system.

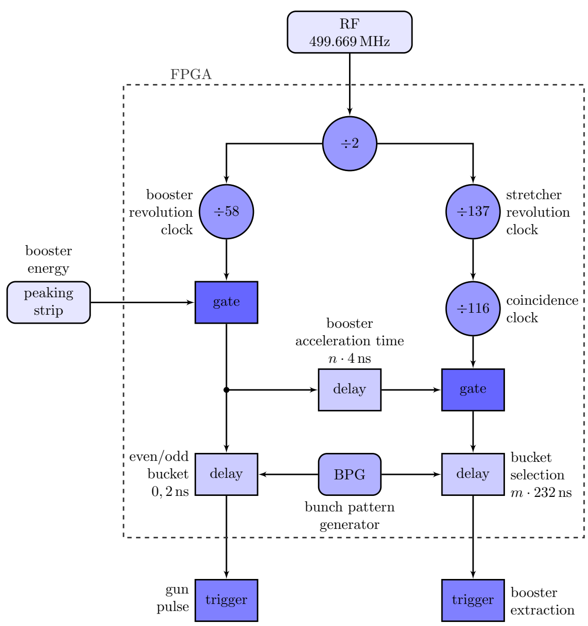

Figure 6: Scheme of the FPGA based timing system.

The timing is driven using the facility master oscillator's RF, operating at a frequency of 500 MHz. The FPGA allows frequency locking onto signals with double it's clock rate which allows to clock the FPGA at 250 MHz. The revolution clocks of the booster and the stretcher, operating with harmonic number 116 and 274 respectively, are derived by dividing the RF by the corresponding harmonic number. The booster's revolution clock is used to gate the trigger signal for electron pulse generation in a way that always the same booster bucket is filled. The so-called peaking strip generates a gate signal when the booster's sinusoidal magnetic field ramp reaches the injection level. This gated trigger signal can be delayed by one bucket length in order to fill either an even or an odd bucket of the booster.

The booster extraction trigger is derived from a coincidence of booster and stretcher revolution clock in order to fill the desired bucket in the stretcher ring. This is achieved by timing the extraction with the coincidence of both accelerator's revolution clocks. This signal is gated with the delayed injection trigger, delayed by the acceleration time of the booster of about 8 ms which depends on the mains frequency. In order to inject into the desired bucket of the stretcher ring the extraction gated signal is delayed by an integer multiple of the booster revolution time. The number of needed turns is calculated by the bunch pattern generator, which contains a pre-calculated delay lookup table of the corresponding coincidences between booster and stretcher revolutions. Selecting the even/odd delay allows to fill an even/odd bucket in the stretcher ring since both, booster and stretcher, have even harmonic numbers. Together with the bucket selection delay, every bucket in the stretcher ring can be filled using this scheme. Specifying the number of injections per bucket and transferring this information to the bunch pattern generator of the FPGA an arbitrary filling pattern in the stretcher ring can be generated.

CONCLUSION

Operating the ELSA stretcher ring at high beam currents requires an upgrade of the Linac 1 towards a high current injector for the booster synchrotron. To increase the injection efficiency into the booster, an improved bunching section and an energy compressing system have been designed. Using an RF waveguide hybrid system allows to drive travelling wave buncher, main linac and energy compressing with individually adjustable RF amplitudes and phases.

Using a new FPGA based timing system for booster injection and extraction timing, the Linac 1 can be used for efficient single bunch accumulation in the stretcher ring.

ACKNOWLEDGMENT

We would like to thank T. Weis for supplying us with the drawings of the phase shifters, forming the basis of our design.

REFERENCES

[1] W. Hillert, Eur.Phys.J. **A28S1**, 139 (2006).

[2] F. Klarner, LINAC08 Conf. Proc., 392 (2009).

[3] F. Klarner, LINAC'10 Conf. Proc., 325 (2010).

[4] *Entwicklung und Bau eines variablen Hochleistungsteilers unter Verwendung von R32-Hybridtechnologie*, Hector Alberto Bendfeldt Hoppe, diploma thesis, TU Dortmund, 1998.