VERIFYING THE SINGLE BUNCH CAPABILITY OF THE NEW INJECTOR AT ELSA*

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Abstract

In order to enhance the operating capabilities of the Bonn University Accelerator Facility, ELSA, a new injector is currently under commissioning. One of its main purpose is to allow a single pulse mode. The injector produces a single electron bunch with 1.5 A pulse current. Design and optimization of the injector have been performed with EGUN, PARMELA and numerical simulations based on the numerical integration of the paraxial equation. A 1 ns long pulse is produced by a thermionic electron source with 90 kV anode - cathode voltage, then compressed and pre-accelerated by a subsequent 500 MHz RF cavity and a four-cell travelling wave buncher. Finally, the bunch will be accelerated to 20 MeV by the main LINAC section. Measurements have been conducted concerning the resulting pulse length and pulse charge to confirm the predictions made by simulations and to investigate the efficiency of the injector system.

MOTIVATION

At the Electron Stretcher Facility at Bonn University, a beam current upgrade from 20 mA to 200 mA is currently planned. Up to the present, it is not possible to obtain a stable beam providing such high intensities. Instabilities are caused either by interactions of electrons in one bunch or collective interactions of the bunches with each other. Examination of single bunch instabilities requires prevention of multi bunch effects through accumulation of electrons in only one bunch in the stretcher ring.

The bucket length of the existing linear accelerating structure (LINAC) is 0.12 ns, which is shorter than the 0.4 ns in the stretcher ring. Therefore, filling only one of the LINAC's buckets with the new injector enables single bunch accumulation in the stretcher ring [1].

Verifying the single bunch capability includes examination of possible overspill into the buckets neighbouring the main bunch. A monitor component consisting of a wall current monitor (WCM) and a beam position monitor (BPM) will be flanged to the beam line exit window for this purpose (see Figure 1). To assure that the equipment on hand has sufficient bandwidth to resolve 0.12 ns pulses, the broadband capabilities of the two monitor devices have been measured using time domain transmissometry (TDT), thereby the monitors' transfer behaviour has been determined (for further reading see [2]).

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THE NEW INJECTOR

The electron gun is based on a design used in the S-Band Test Facility at DESY. Modifications include a triode layout to generate an 1 ns pulse. Emission characteristics of the gun have been optimized by simulating the beam propagation with EGUN to fulfil the requirements of single pulse operation with $I = 1.5\,\mathrm{A}$ beam current, while providing long pulse capability with $I = 0.8\,\mathrm{A}$ for the upcoming beam current upgrade in the stretcher ring.

Bunching is achieved by a 500 MHz subharmonic prebuncher and a 3 GHz travelling wave buncher (TWB). To prevent phase shifts between the different structures, they, together with the LINAC, are powered by one 500 MHz, 2 W continuous wave source.

The particle ensemble adopts the sinusoidal TM_{010}-mode of the prebuncher as an energy modulation. Thereby, a zone of maximum particle density is formed after a drift distance of 34 cm. The first of the TWB's four cells is placed after the drift distance behind the prebuncher. This structure further compresses the bunches and boosts the initial particle velocity of $\beta_{in} = 0.526$ to the phase velocity $\beta_{ph} = 1$ of the accelerating LINAC. The electron velocity at the exit of the TWB is $\beta_{out} = 0.85$. Therefore, the bunch length is nearly fixed form here on.

The optimization of phase relations and field strengths between the gun, the bunching structures and the LINAC have been performed through iterative matching of their parameters in PARMELA to achieve a final bunch compression to 0.1 ns. The simulated bunches have Gaussian shape and lengths of $2\sigma = 1$ ns behind the electron gun, $2\sigma = 0.4$ ns at the exit of the prebuncher and the desired $2\sigma = 0.1$ ns behind the TWB [1].

THE LINEAR ACCELERATOR STRUCTURE

The LINAC is a disc loaded wave guide with a constant gradient of $7.9\,\mathrm{MV\,m^{-1}}$ and a phase advance of $2\pi/3$ per cell. It uses an operation frequency of 3 GHz and can accelerate $I = 0.8\,\mathrm{A}$ current up to $E = 20\,\mathrm{MeV}$. The bucket length for electrons with a velocity of $\beta = 0.85$ is about 0.12 ns. If the bunch length will be compressed to $2\sigma = 0.1$ ns with the commissioning of the TWB, more than 95% bunch capturing efficiency in one bucked is going to be achieved.

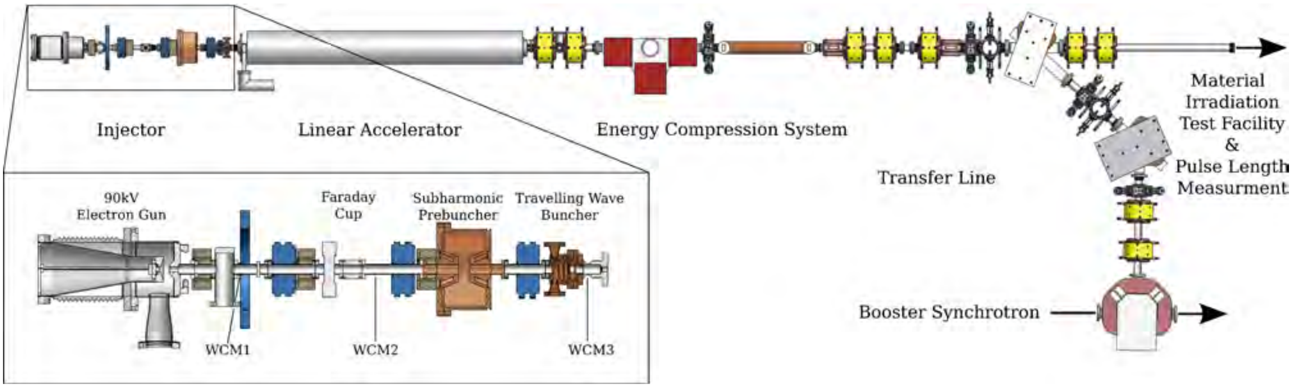

Figure 1: The new linear accelerator Facility at ELSA.

MEASUREMENTS

The beam transfer into the synchrotron is currently under construction. In the meantime, the structure serves as a material irradiation test facility, only operating in long pulse mode with low beam currents. Initial beam diagnostics show good agreement between measured and predicted pulse currents and shapes.

The Pulse charge is measured using a coaxially designed Faraday cup matched to $50\,\Omega$ (see Figure 1). The bunches Gaussian shape is confirmed by the voltage signal and the predicted maximum beam current holds $I_{\text{max}} = (1.406 \pm 0.042)$ A [1].

Three WCMs have been installed at different positions along the beam line (see Figure 1). The pulse lengths are first $2\sigma = (1.02 \pm 0.04)$ ns behind the electron gun, then $2\sigma = (1.08 \pm 0.04)$ ns before the prebuncher and finally $2\sigma = (0.41 \pm 0.04)$ ns at the LINAC entrance [1]. Since the TWB is still under commissioning, 0.1 ns pulse length cannot be achieved. Nevertheless, the impact of the bunching system is apparent.

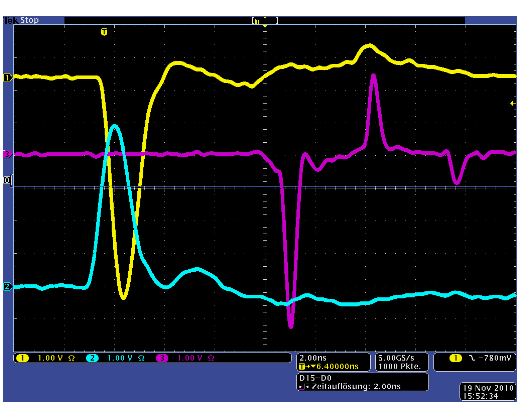

Figure 2: WCM1 (yellow), WCM2 (blue) and WCM3 signal (magenta) on an oscilloscope (for the locations see Figure 1). The absolute signal positions depend on the cable length, the signal polarities depend only on which way the connector is actually linked to the WCMs.

PULSE LENGTH BEHIND THE LINAC

To verify that only one bucket is filled in the LINAC, a pulse length measurement behind the linear accelerator is necessary. Since the LINAC has a period length of $T = 0.3$ ns, pulses preceding and succeeding the main 0.1 ns pulse by only 0.3 ns have to be examined. This requires measuring equipment with sufficient bandwidth.

Testing of the existing monitor components' frequency resolution has been carried out with a dedicated TDT setup (see Figure 3). A network analyzer generates synthetic Gaussian pulses with bandwidths from 3 kHz up to 8 GHz. The signal is directed to a coaxially designed BPM and WCM test device. The inner conductor represents the electron beam[1]. Cones at both ends of the device reduce signal reflections.

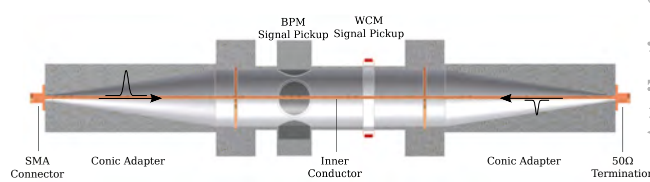

Figure 3: TDT setup.

The transmitted signal is used for calibration. This results in the reference Gaussians[2] shown in Figure 4.

After the calibration, the inner conductor is terminated with $50\,\Omega$ to dampen reflections. The analyzer's entrance is then connected to the monitors' pickups to get their response to the Gaussian pulse. The signals for swept bandwidths from the monitors are shown in Figure 6 and Figure 5.

Despite the cones and the terminating resistor, some reflections still distort the right flank of the signals. Therefore, the signal profile has to be acquired from the left flank only. The signal from the WCM shows the slope emphasis

[1] The field configuration of TEM modes is equal to the one of an electron beam.

[2] The lower cutoff frequency of the network analyzer causes band pass behaviour, hence the ripple in the calibration signal.

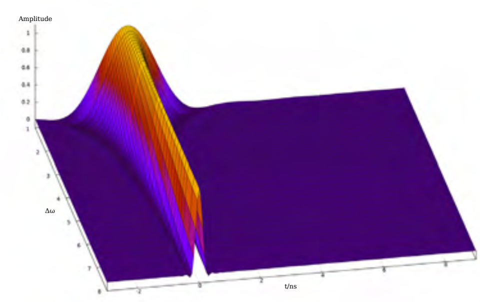

Figure 4: Gaussian pulses with rising bandwidth, $\Delta\omega$, transmitted through the monitor.

of a high pass filter with pronounced overshoots while simultaneously dampening higher frequencies like a low pass filter. Overall, its transfer function represents a band pass filter.

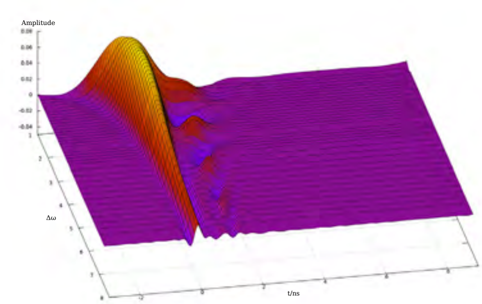

Figure 5: Response of the WCM to the rising bandwidth of the incoming Gaussian pulse.

The BPM reverses the signal polarity in an intermediate bandwidth range from 3 GHz to 5 GHz. This might be caused by a band stop component in the monitor's transfer function.

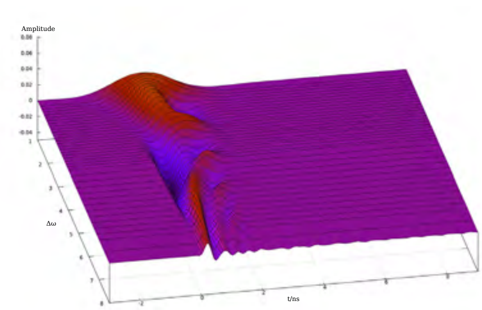

Figure 6: Response of the BPM to the rising bandwidth of the incoming Gaussian pulse.

Since the network analyzer is only capable of producing Gaussian pulses with a maximum bandwidth of 8 GHz, examinations of shorter pulses in the time domain have been done with simulations based on the measured transfer behaviour of the monitor.

Two simulated Gaussians with $2\sigma = 0.1$ ns, one a quarter the amplitude of the other, with a delay of 0.3 ns, have been Fourier transformed and multiplied with band pass filters of different bandwidths. The result is then inverse Fourier transformed and shown in Figure 7. Altogether, this simulates substantial overspill in a preceding bucket, measured by the WCM behind the LINAC.

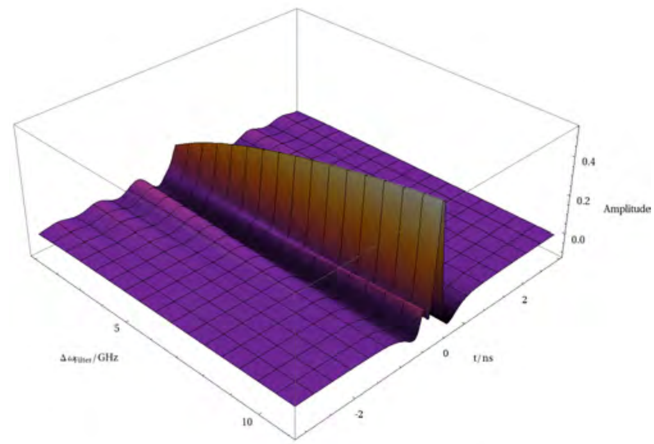

Figure 7: $\mathcal{F}^{-1}\left(\mathrm{BandPass} \times \mathcal{F}\left(\mathrm{Gaussians}\right)\right)$ for different bandwidths of the band pass, $\Delta\omega_{\mathrm{Filter}}$.

The Gaussian with lower amplitude can be detected as a separate peak upon the filter reaching $\Delta\omega_{\mathrm{Filter}} = 5$ GHz. Since $2\sigma = 0.4$ ns pulses have already been reproduced using a similar WCM without indications of bandwidth restrictions (see Figure 2), we are optimistic that the WCM has sufficient bandwidth to detect significant overspill in neighbouring buckets.

CONCLUSION

A new injector has been designed and constructed to provide both single bunch accumulation and high beam currents at the ELSA facility. The design is based on a conservative scheme using a thermionic high intensity pulsed gun, one subharmonic buncher cavity and a travelling wave buncher. The bunches are expected to be compressed to 0.1 ns before entering the linear accelerator. First measurements in the injector have been executed, showing promising results concerning the predicted bunch shape and charge. For further measurements, it has been established that available equipment is sufficient to determine the longitudinal beam structure behind the LINAC.

REFERENCES

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