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BUNCH COMPRESSION OF THE LOW-ENERGY ELBE ELECTRON BEAM FOR SUPER-RADIANT THz SOURCES

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Abstract

At the ELBE radiation source two super-radiant THz sources, a broad-band trasnsition/diffraction radiation source and a planar undulator narrow-band source are under commissioning. At present the facility is driven from the ELBE linac with a CW electron beam of 100 kHz repetition rate and up to 100 pC of bunch charge. With the upgraded SRF electron gun bunch charges up to 1 nC will become available. For the beam energies in the 20-30 MeV range buch compression into the sub-200 fs range becomes a major challenge. We present beam dynamics calculation of the attempted bunch compression scheme as well as first measurements obtained during the commissioning.

INTRODUCTION

The ELBE Center at HZDR develops and operates accelerator-based radiation sources. Since 2005 ELBE is operated as a user facility being open to users world-wide. The main sources are two free electron lasers operating in the IR/THz regime. The great success of these devices was followed by an ever increasing user demand particularly for the long-wavelength range. This led to the decision to install two new THz sources (one broad-band and one narrow-band) utilizing coherent transition or diffraction radiation and an 8 period undulator covering the wavelength range from several millimeters down to 100 μm (3 THz). Both new sources are operated in the super-radiant regime requiring the compression of the electron bunch to a length shorter than the requested wavelength.

BUNCH COMPRESSION SCHEME

Creating short bunches at the low beam energy of typically 24 MeV usually requires a trade-off between several conflicting parameters. In the injection region a compression to rather short pulses usually is beneficial for the longitudinal emittance. The short pulses, however, subsequently suffer from larger (non-linear) energy modulation due to longitudinal space charge. In addition, for pulses well below 2 ps the second Linac cannot introduce enough chirp for full bunch compression due to ist limited gradient. Thus, we stretch the beam with a first magnetic chicane before entering the second Linac. There we apply as much chirp as possible, only limited by the chromaticity of the beam transport and the resulting loss of the energy-fringe particles. A rather weak magnetic chicane is then used to finally compress the beam to yield super-radiant radiation from mm waves up to 3 THz. Fig. 2 illustrates this general scheme.

BEAM DYNAMICS

Longitudinal Emittance Optimization for the Thermionic Injector

Achieving short bunches with the ELBE electron beam crucially depends on the longitudinal emittance. This emittance is mainly formed in the injector and during the capture of the beam into the first accelerating cavity. To optimize the operation of our machine we have modeled the injection region using ASTRA [1]. We have found systematic dependencies of the tuning parameters on the bunch charge, in particular the buncher voltages, which have not been observed yet when tuning the real machine.

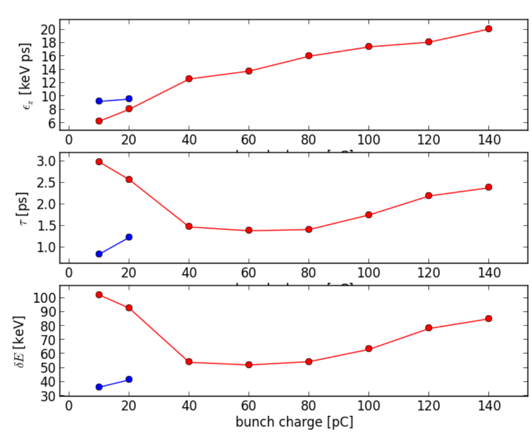

Figure 1: Optimized bunch parameters from ASTRA simulations of the injection to the exit of the first Linac. For very low bunch charges a second solution is shown in blue which sacrifices some of the emittance value for the benefit of a shorter, less correlated bunch with lower energy spread.

Most of the THz beamtime so far was run with the 80 pC setting. For higher bunch charges we were not yet able to demonstrate the according increase in THz output which must be attributed to an increase in longitudinal emittance beyond that one shown in the simulations.

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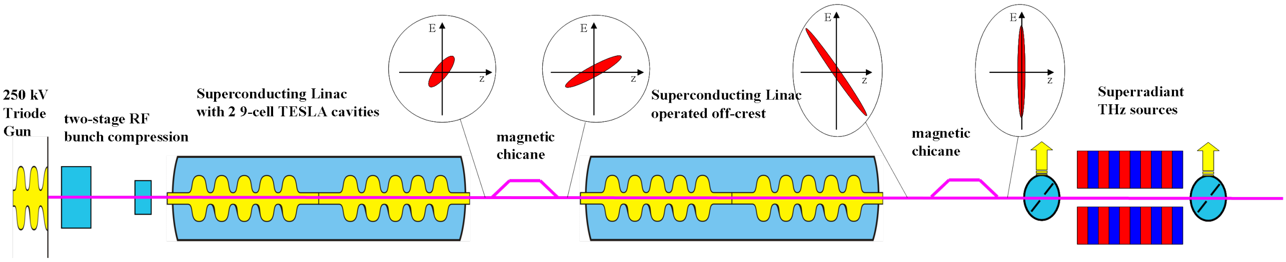

Figure 2: Bunch compression scheme of the ELBE THz facility using the thermionic injector. In between the two accelerator cryomodules a magnetic chicane is operated as a stretcher. The second accelerator module is operated off-crest to obtain a chirped beam which is then compressed by a second magnetic chicane to generate super-radiant pulses in the THz region.

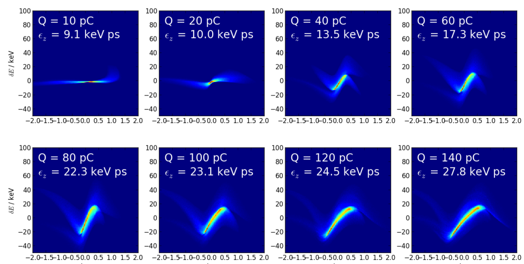

Figure 3: Longitudinal phase space from ASTRA simulations of the injection to the exit of the first Linac. A slope of 200 keV/ps has been removed from all distributions in order to more clearly show the influence of the longitudinal space charge.

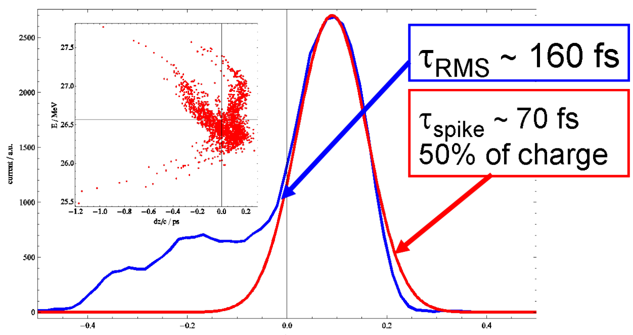

Figure 4: Bunch profile for an 80 pC bunch at 24 MeV obtained from a PARMELA/CSR-Track calculation. The leading half of the particles form a 70 fs spike.

Bunch Profile of the Compressed Beam

Due to the non-linear RF acceleration field the bunch usually acquires a curved shape in the longitudinal phase space. Unless this nonlinearity is corrected it is not possible to compress the whole bunch into a very short pulse. At ELBE we attempt to compress just the central part of the bunch into a short spike with the particles in the energy fringes forming a longer tail. Beam dynamics simulations done with PARMELA [2] and CSR-Track show that it should be possible to generate bunches with a sub-100 fs leading spike and an overall (RMS) bunchlength below 200 fs. Recently, coherent undulator radiation has been observed up to 3.5 THz proving the existance of a short spike in the bunch profile. The fraction of charge in this spike (the form factor), however, not yet reaches the 50% value indicated by the simulations.

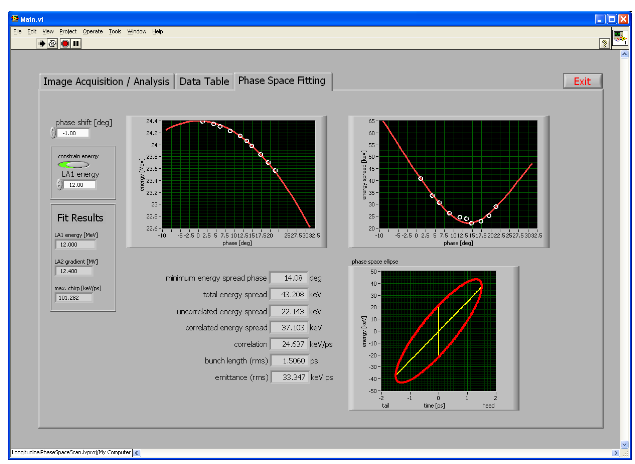

Figure 5: Longitudinal phase space measurement with a cavity-phase scan. The left panel shows the beam energy, the upper right one the measured energy spread and the lower panel the obtained phase space ellipse.

BEAM PARAMETER MEASUREMENTS

Longitudinal Emittance

For a measurement of the longitudinal emittance we scan the phase of the second linac and measure the enrgy spectrum of the beam with a dipole magnet shortly after the Linac exit. This way we can study the longitudinal phase space out of the first linac and the action of the first chicane operated as a strecher. The bunchlength measured this way correlates with bunchlength measurements performed with electro-optic sampling and with a Martin-Puplett interferometer. The action of the chicane is not yet fully understood. Simulations with ELEGANT show a significant modulation of the buch energy profile by longitudinal space charge fields which may explain some of the observed discrepancies. The obtained emittance value after tuning the injection for optimized THz output, however, is well in line with the sim-

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ulation results. Measurements of the bunchlength presented in [3] also roughly agree with the results obtained here.

Bunch Length

At present the best possible diagnostics of the compressed electron bunch is the analysis of the THz radiation from broad-band diffraction or transition radiation sources. These measurements are described in [4] in greater detail.

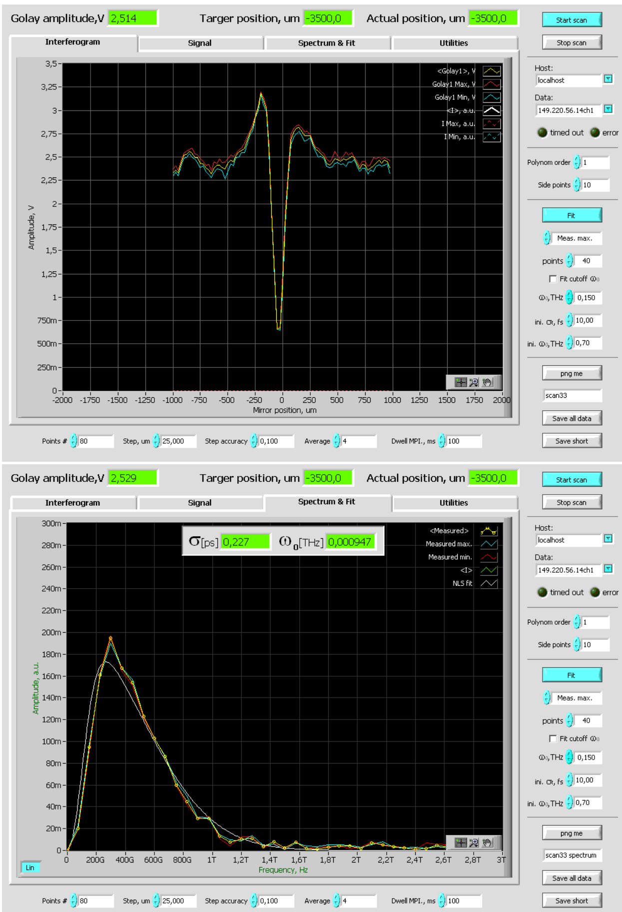

Figure 6: Autocorrelation and spectrum of the compressed electron bunch measured with an interferometer downstream of the THz undulator. The beam was tuned for overall compression, not for a short spike.

One method to determine the length of the compressed electron bunch uses an FIR interferometer measuring the autocorrelation of the coherent transition radiation emitted from a beam viewer. For the measurement presented here we have used a device designed and used in routine operation at Jefferson National Laboratory. We have obtained values down to the 200 fs region which roughly corresponds to both the beam dynamics calculations as well as measurements of THz emission from the undulator.

CONCLUSION

We have demonstated that a bunch compression of the low-energy ELBE electron beam into a short bunch suited for super-radiant THz sources is possible. While we can achieve a near-unity form factor for the sub-1 THz region, the spike-mode operation needed for the shorter wavelengths still needs some improvements.

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