SLICE-EMITTANCE MEASUREMENTS AT ELBE / SRF-INJECTOR*

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Abstract

The linear accelerator ELBE delivers high-brightness electron bunches to multiple user stations, including two IR-FELs. The current thermionic injector is being amended by a superconducting rf photoinjector (SRF-injector) which promises higher beam quality. Using an injection beamline, beam from the SRF-injector can be injected into the ELBE linac. Detailed characterization of the electron beam is achieved by measuring the vertical slice emittance of the beam. To perform this measurement a combination of rf zero-phasing, spectrometer dipole and quadrupole scan is used. The electron beam is accelerated by the first cavity of the ELBE accelerator module and sent through a second cavity which is operated at zero-crossing of the rf. In doing so a linear energy-time correlation is induced in the beam. The chirped beam is sent through a spectrometer dipole and the longitudinal distribution can be made visible on a scintillator screen. Performing a quadrupole scan allows the determination of the emittance for different slices. This paper explains the working principle of the method, the experimental setup and presents first results for both simulations and measurement.

INTRODUCTION

The linear accelerator ELBE delivers high-brightness electron bunches to multiple user stations, including two IR-FEL oscillators [1]. In the framework of an upgrade program the current thermionic injector is being replaced by a SRF-photoinjector [2], [3]. The SRF-injector promises higher beam quality, especially required for future experiments with high power laser radiation. During the commissioning phase, the SRF-injector was running in parallel to the thermionic gun. After installation of a injection beamline (dogleg), beam from the SRF-injector can now be injected into the ELBE linac. Detailed characterization of the electron beam quality delivered by the new electron injector includes vertical slice emittance measurements in addition to measurements of projected emittance values.

ZERO-PHASING TECHNIQUE

Generally, the longitudinal electron distribution has to be converted to a transverse distribution to allow the measurement of slice emittance values. This can be done using the zero-phasing technique in combination with a spectrometer dipole. Fig. 1 shows the working principle of the method schematically. The accelerated electron bunch passes a second cavity at zero-crossing of the accelerating rf field. In doing so one induces a linear time-energy correlation in the bunch. The chirped electron pulse is sent through a spectrometer dipole which then converts the longitudinal distribution to a transverse distribution. A scintillator screen behind the spectrometer is used to make the beam distribution visible. Due to the induced energy chirp each transverse position on the screen corresponds to a temporal position in the bunch. The longitudinal slices of the electron bunch are accessible. A combination of the zero-phasing technique and the common quadrupole scan technique allows emittance measurements for individual longitudinal slices.

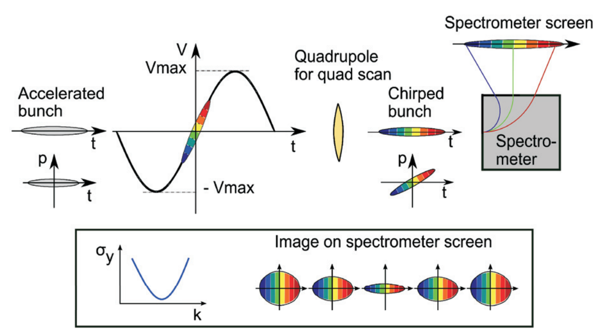

Figure 1: Working principle of the zero-phasing technique

MEASUREMENT SETUP AT ELBE

Fig. 2 shows the setup of the ELBE beamline, including SRF-injector and dogleg, schematically. Additionally it summarizes the components directly used for the measurement and their purpose. The ELBE accelerator consists of two accelerating modules each with two cavities. The first cavity of the first accelerator module is used for acceleration of the beam optimized for maximum energy and the second cavity is operated off-crest in order to create the required time-energy correlation. To complete the zero-phasing measurement setup the ELBE beamline has been upgraded by the inclusion of a spectrometer magnet. The spectrometer is placed in the straight non-dispersive section after the accelerator module and the quadrupole triplet. The second and third quadrupole following the first ELBE accelerator module have been used to perform the quadrupole scan.

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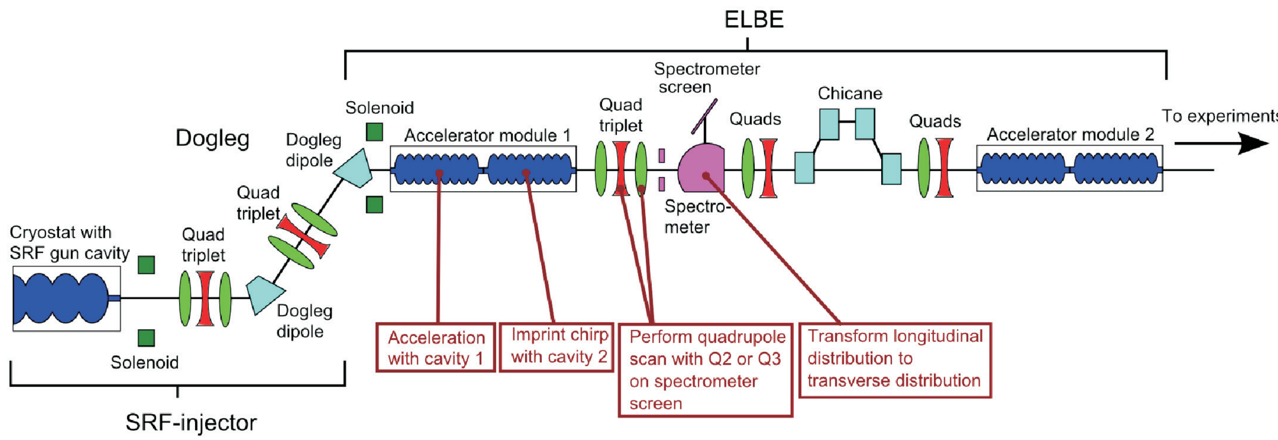

Figure 2: Schematics of ELBE beamline with SRF-injector and setup for slice emittance measurements

'Browne-Buechner' Spectrometer

The dipole spectrometer implemented is a 'Browne-Buechner'-magnet [4]. The spectrometer has a uniform magnetic field with circular boundary of radius R and a deflecting angle of 90°. Its unique imaging properties cover a broad range of beam energy. A divergent source when placed a distance R from the boundary of the field is focused onto a hyperbolic surface. Reference energy particles are focused with an image length equal to R . Due to the spectrometers imaging properties a high energy resolution can be achieved. For beam energy of 18 MeV and a slit width of 0.1 mm FWHM the resolution has been estimated to be 3 keV. Fig. 3 helps clarify the imaging properties of the spectrometer schematically.

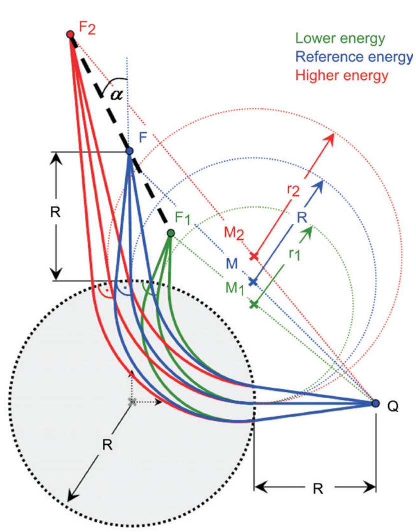

Figure 3: Imaging properties of the "Browne-Buechner" spectrometer

FIRST MEASUREMENT RESULTS

First measurements were performed at beam energy of 18 MeV and bunch charge of 10 pC for different gun cavity and chirp cavity rf phase combinations. The beam parameters and phase combinations are given in Tab. 1. Here 0° refers to the zero-crossing of the rf wave. A cathode dc voltage of 5 kV has been applied during the measurement. Energy-dependent transfer matrices were used to analyse 5 slices of the beam. Fig. 4 shows the emittance results for measurement series 6. It shows the average longitudinal beam profile reconstructed from the screen images overlayed by bars representing the slice position and the corresponding emittance values. The error bars result from the least squares fit applied to the relation between squared rms beam size and quadrupole strength. No additional error sources, e.g. due to image analysis, have been included here. The slice emittance values are correlated to the longitudinal intensity profile which may be explained by space charge effects that cause transverse beam size growth. A summary of all measured slice emittances is given in Fig. 5. Here the measurement series are labeled according to Tab. 1 and the slices are numbered from head to tail of the bunch. As explained for Fig. 4, the error bars represent the error estimated from the fitting procedure only. Generally, the measured slice emittances vary between 0.5 mm mrad and 2 mm mrad. The emittances fol-

Table 1: Phase Settings and Beam Parameters

Meas. series	Beam energy (MeV)	Bunch charge (pC)	Gun cav. phase (°)	Chirp cav. phase (°)
1	17.6	10	0	108
2	17.6	10	0	66
3	17.9	10	10	66
4	18.0	10	-10	66
5	18.1	10	-10	66
6	17.8	10	-10	60

low the longitudinal intensity and are lower for the outer slices. It is obvious that a gun phase of $-10°$, as in series 4, 5 and 6, leads to lowest overall emittance and less emittance variation along the bunch compared to measurements performed at $0°$ and $10°$ gun phase. This phase dependence could not yet be verified by simulation and is under investigation.

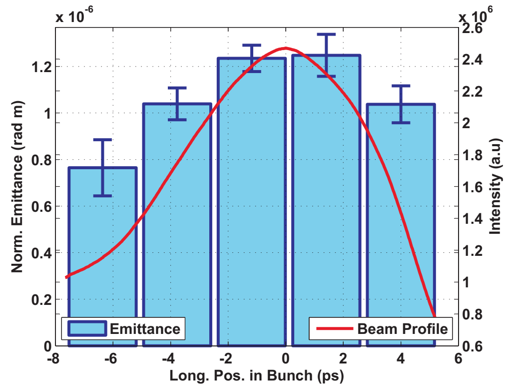

Figure 4: Measured slice emittances, series 6

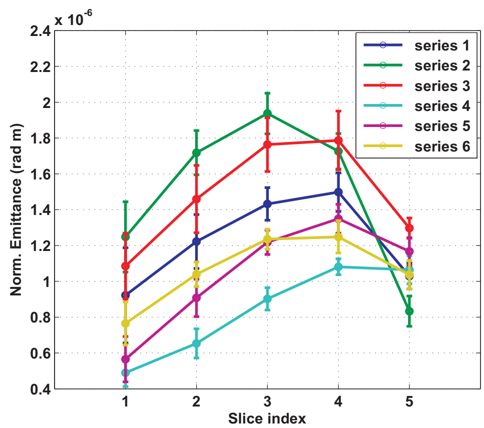

Figure 5: Slice emittance measurement results

PRELIMINARY MEASUREMENT SIMULATIONS

Simulations of the measurement have been performed using 'ASTRA' [5] and 'elegant' [6]. The electron gun simulations including cathode dc field, cavity rf and solenoid field have been calculated using ASTRA. ASTRA calculations end at the first quadrupole after the electron gun. Output from ASTRA was transferred to elegant to simulate the measurement procedure itself. The same data analysis procedure as used for the measurement analysis was applied. The slice emittance values determined by simulation are consistently lower than measured values. This may be due to space charge effects that have been excluded from the simulation. Simulated values lie between 0.5 mm mrad to 1 mm mrad. A direct comparison from simulation to measurement results for an exemplary measurement series is given in Fig. 6. Though the simulated emittances lie below the measured values, both the measured and simulated values show similar characteristics with respect to the longitudinal slice position. The cause of the size of the error bars resulting from the fitting procedure in the simulation case is still under investigation.

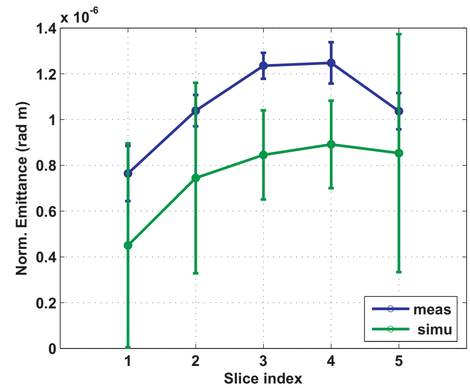

Figure 6: Comparison of slice emittance values determined from measurement and simulation, series 6

SUMMARY

First slice emittance measurements at the ELBE SRF-injector have been performed and demonstrated the zero-phasing technique to be a promising diagnostics tool. Slice emittance values between 0.5 and 2 mm mrad have been measured. Preliminary simulation results are lower than measured data and lie between 0.5 and 1 mm mrad and show the characteristics of the measurement. Further detailed investigations concerning simulations in order to provide an adequate model for the measurements are needed and foreseen. A second measurement period is planned to perform phase dependent slice emittance studies and detailed studies at higher bunch charges, including on line beamline modeling.

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