FIRST OPERATION OF THE ELBE LINEAR ACCELERATOR

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Abstract

The new radiation source ”Strahlungsquelle ELBE” at the Forschungszentrum Rossendorf (FZR) will use the high brilliance electron beam from a linac with superconducting rf-cavities to produce various secondary beams for experiments in nuclear science, solid state physics, materials research, environmental chemistry and in the life sciences. During the year 2001 all components belonging to the first stage of ELBE (20 MeV) were successfully put into operation. The main beam properties were measured and it was shown that all major design parameters could be reached with the ELBE accelerator. In the low bunch charge mode of operation intended for radiation physics applications a transversal emittance of $3\,\pi$ mm mrad was measured. At the 77 pC maximum bunch charge the emittance is still better than $10\,\pi$ mm mrad, well sufficient for driving the ELBE free-electron lasers. The longitudinal phase space properties are mainly defined by the capture process of the electron bunches into the first accelerator cavity and could, thus, be characterized by measuring the energy spectrum of the beam while scanning the rf-phase of the second cavity. These measurements at 3 pC bunch charge yielded an emittance of $57\,\pi$ keV ps and a bunch-length of 2 ps, in good agreement with theoretical predictions and with bunch length measurements using an auto-correlation technique.

1 THE ELBE FACILITY

At the Forschungszentrum Rossendorf (FZR) the radiation source ELBE is being built to become a user facility for various research using electromagnetic radiation. Its heart is a superconducting Electron Linac with high Brilliance and low Emittance [1]. It will deliver a 40 MeV electron beam with up to 1 mA cw beam current. A grid-pulsed 250 kV thermionic gun followed by a two-stage RF bunch compression serves as injector. Two cryomodules each containing two nine-cell superconducting cavities are operated at 1.8 K. The DESY-TTF-type niobium cavities are driven by 10 kW klystron amplifiers at 1.3 GHz yielding accelerating gradients above 10 MV/m. A magnetic chicane installed between the two accelerator modules allows a further bunch compression down to 1 ps bunch length.

The linac will be used to drive free-electron lasers producing infrared light in the 5-150 μm wavelength region. Additionally, from several conversion targets MeV-bremsstrahlung, X-rays from electron channeling, neutron and even positron beams will be available. The planned layout of the facility is shown in Fig. 1.

During the year 2001 the first stage of the ELBE linac was successfully put into operation. Main electron beam parameters like energy, energy spread, bunch length and the transverse and longitudinal emittance were measured. Moreover, optimal machine operating parameters were specified and several online diagnostic tools necessary for routine high-power operation were tested. During year 2002 now the nuclear spectroscopy and radiation physics beamlines will be set up for first experiments. First operation of a free electron laser is planned for 2003.

2 ELECTRON BEAM PARAMETERS

The injector of ELBE operating at $\beta = 0.74$ to a large part determines the achievable beam parameters. So, the transverse emittance was found to be essentially the same at the accelerator exit as measured inside the injector, mainly governed by the thermionic gun (see Fig. 2). For emittance measurements at the injector beam alternatively a pepper-pot mask or a solenoid-scan method have been used, with both methods yielding identical results.

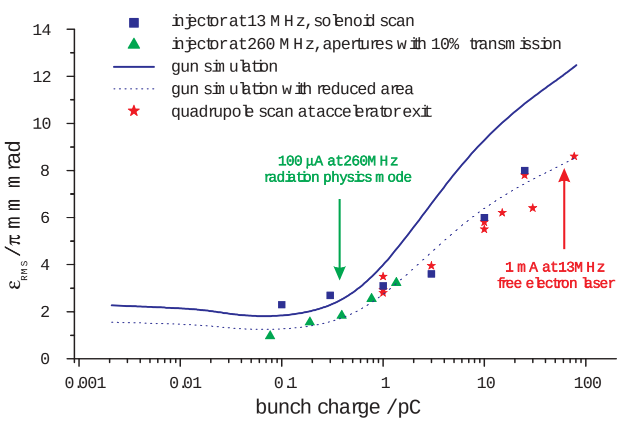

Figure 2: Transverse emittance of the electron beam for varying bunch charges.

The bunch compression in the injector also influences the capture process of the beam into the first accelerator cavity. Therefore, the longitudinal beam parameters energy spread and bunch length but also the transverse emittance depend sensitively on the relative phase between injector and accelerator RF. At high bunch charges they yield min-

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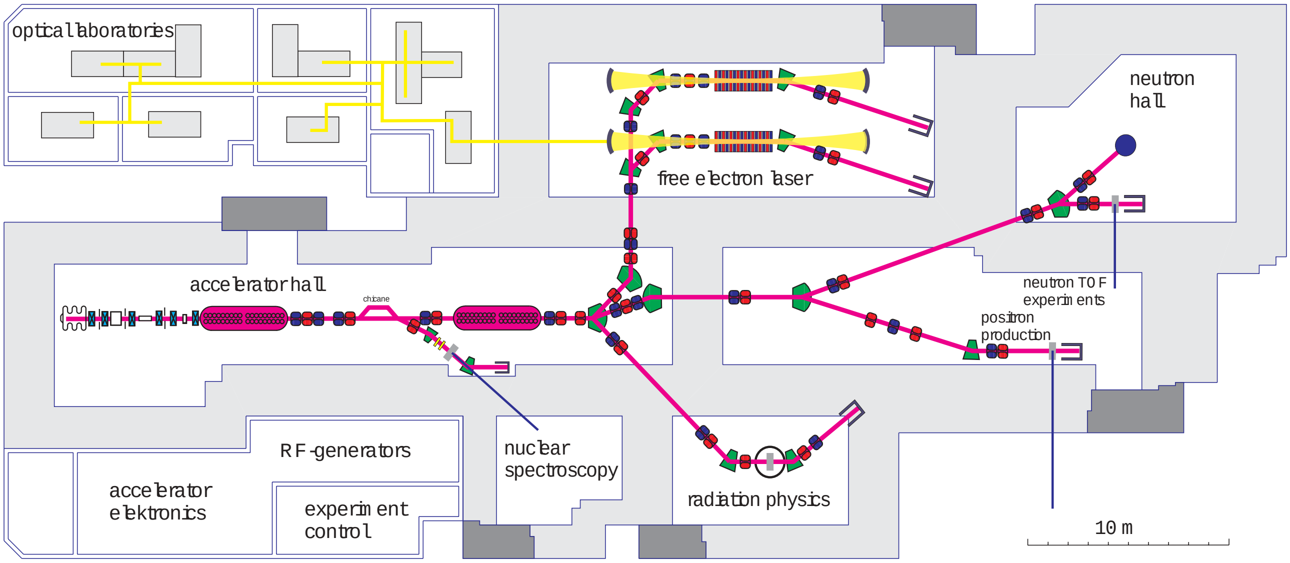

Figure 1: Overview of the ELBE facility.

ima at different phases, requiring a compromise for the actual setup (see Fig. 3).

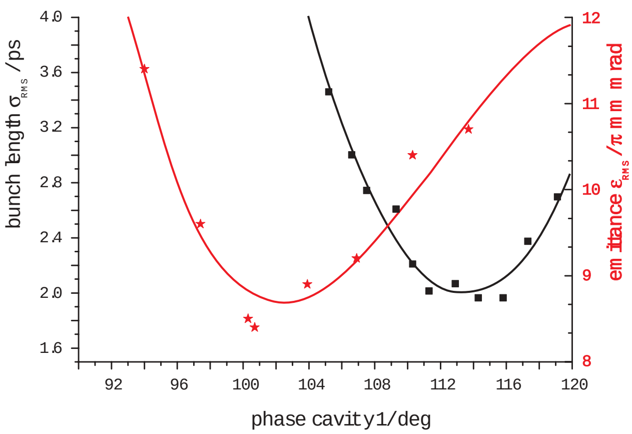

Figure 3: Bunch length and transverse emittance of the electron beam for varying first-cavity RF phase.

Fig. 4 shows the results of emittance measurements performed at the exit of the accelerator module. In this case a quadrupole-scan method was applied, which also allowed to derive the actual shape of the phase-space ellipse. An overview of the achieved beam parameters is given in Table 1.

3 BUNCH LENGTH MEASUREMENTS

A direct measurement of the electron bunch length is possible using far-infrared coherent transition radiation (CTR) which is emitted when the electron beam passes a thin aluminum foil. The response time for the radiation production process is essentially zero. Therefore, the radiation pulse is an exact copy of the electron bunch. We are using a Martin-Puplett interferometer to measure the

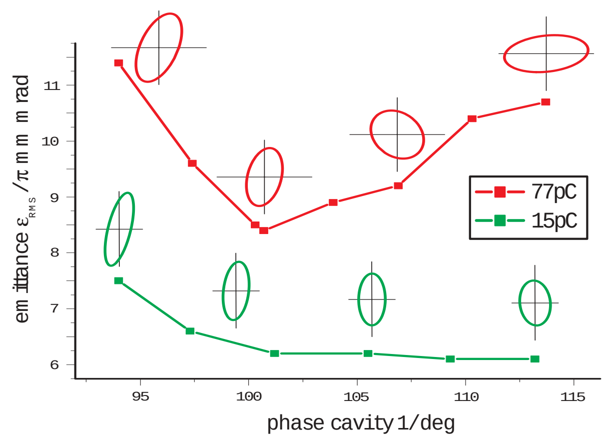

Figure 4: The transversal phase space of the ELBE electron beam.

autocorrelation function of this CTR pulse (see Fig. 5). From the autocorrelation function the power spectrum of the CTR emission can be calculated. The bunch length can then be determined by comparison with power spectra of beams of suspected shape and size.

The bunch length was studied for different bunch charges as a function of the first-cavity RF-phase, which essentially influences the capture process of the bunch into the accelerator. At the full bunch charge of 77 pC a bunch length of minimal 2 ps was achieved. Fig. 6 shows the results of the measurements.

4 LONGITUDINAL PHASE-SPACE MAPPING

The bunch shape of the electron beam is essentially fixed after reaching relativistic energies during the capture pro-

Table 1: Measured properties of the ELBE electron beam

<table>
<tr><td colspan="2">maximum beam energy
maximum beam current
maximum bunch charge</td><td colspan="2">20 MeV
0.85 mA at 20 MeV
77 pC</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">at 1 pC bunch charge</td><td colspan="2">at 77 pC bunch charge</td></tr>
<tr><td>simultaneously achievable</td><td>best achieved</td></tr>
<tr><td>energy spread ΔE_{FWHM}
transverse emittance ϵ_{RMS}
bunch length σ_{RMS}</td><td>35 keV
3 π mm mrad</td><td>55 keV
10 π mm mrad
2.5 ps</td><td>40 keV
8 π mm mrad
2.0 ps</td></tr>
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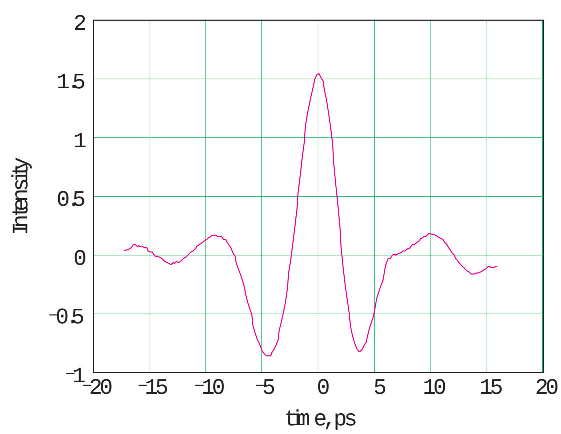

Figure 5: Autocorrelation function of the ELBE electron bunch measured with a Martin-Puplett interferometer.

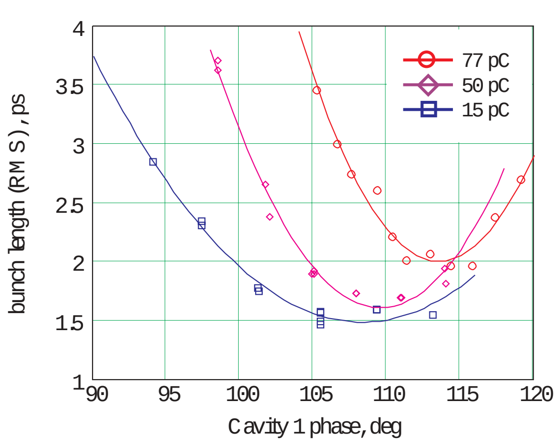

Figure 6: Measured bunchlength for varying RF-Phase of the first accelerator cavity.

cess into the first accelerator cavity. As the ELBE accelerator module comprises two cavities this offers the opportunity to use the second cavity to characterize the beam at the exit of the first one.

At the exit of the accelerator module a dipole magnet is used to measure the energy distribution of the beam. Several measurements were performed while scanning the phase of the second accelerator cavity off the crest, adding a time dependent energy shift to the bunch. From the measured energy spectra, applying a tomographic reconstruction algorithm, the complete longitudinal phase space information can be obtained.

At 3 pC bunch charge a longitudinal emittance of 57 π keV ps and a 2.2 ps bunch length were determined with this method.

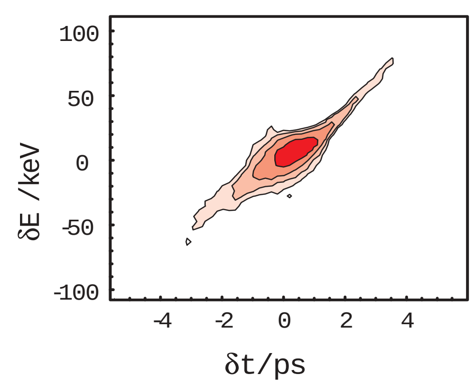

Figure 7: The longitudinal phase space of the electron beam at the exit of the first accelerator cavity.

5 REFERENCES

[1] http://www.fz-rossendorf.de/FWQ/