Karlsruhe Institute of Technology

Accelerator Technology Platform @ KIT

Effect of Negative Momentum Compaction Operation on the Current-Dependent Bunch Length

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Motivation

- Future low emittance rings could benefit from negative momentum compaction operation
- Reduced sextupoles possible and result in higher dynamic aperture
- Understanding of involved effects is necessary
- KARA as test facility allows studies in this regime

$$\alpha_c = \frac{\Delta L/L}{\Delta p/p} = \frac{1}{L}\oint \frac{D(s)}{\rho(s)}\mathrm{d}s$$

Lattice and Optics

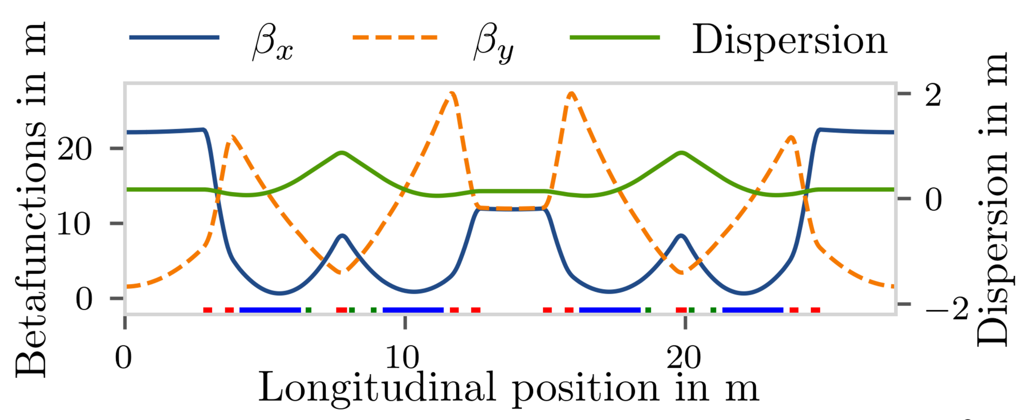
KARA

- 4 fold symmetry
- 2 double bend achromats per cell
- 5 quadrupole magnets per DBA (Q1-5)
- Straight sections are filled with insertion devices, RF stations and injection magnets

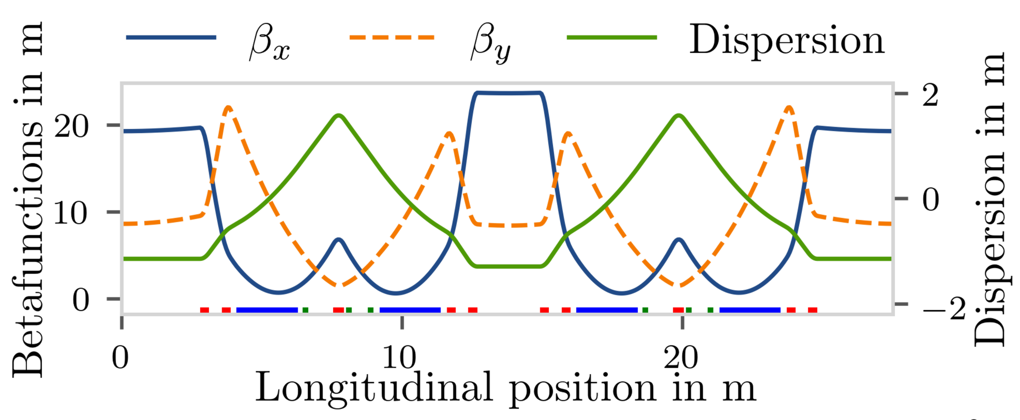
Parameter	Value
Energy	0.5 – 2.5 GeV
Circumference	110.4 m
RF frequency	500 MHz
Revolution frequency	2.715 MHz
$\sigma_{z,\,\mathrm{RMS}}$ (standard operation, 2.5 GeV)	45 ps
$\sigma_{z,\,\mathrm{RMS}}$ (short bunch mode, 1.3 GeV)	few ps

Operation Modes

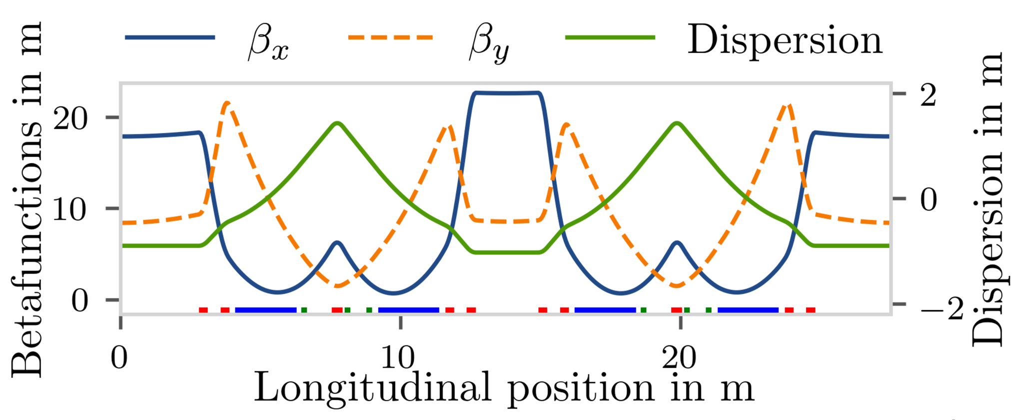
- Standard operation at 2.5 GeV and $\alpha_c \approx 9\times10^{-3}$
- Short bunch mode at 1.3 GeV and $\alpha_c \approx 1\times10^{-4}$
- New modes:
  - Negative α_c at 0.5 GeV and various α_c
  - Negative α_c at 0.9 GeV and various α_c
  - Negative α_c at 1.3 GeV and various α_c



Calculated lattice used for user operation at $\alpha_c = 9\times10^{-3}$ and 0.5 GeV. The bottom depicts the magnets, quadrupoles in red, sextupoles in green and bends in blue.



Calculated lattice for a negative value of $\alpha_c = -1.2\times10^{-3}$ at 0.5 GeV. In large parts the dispersion is negative.



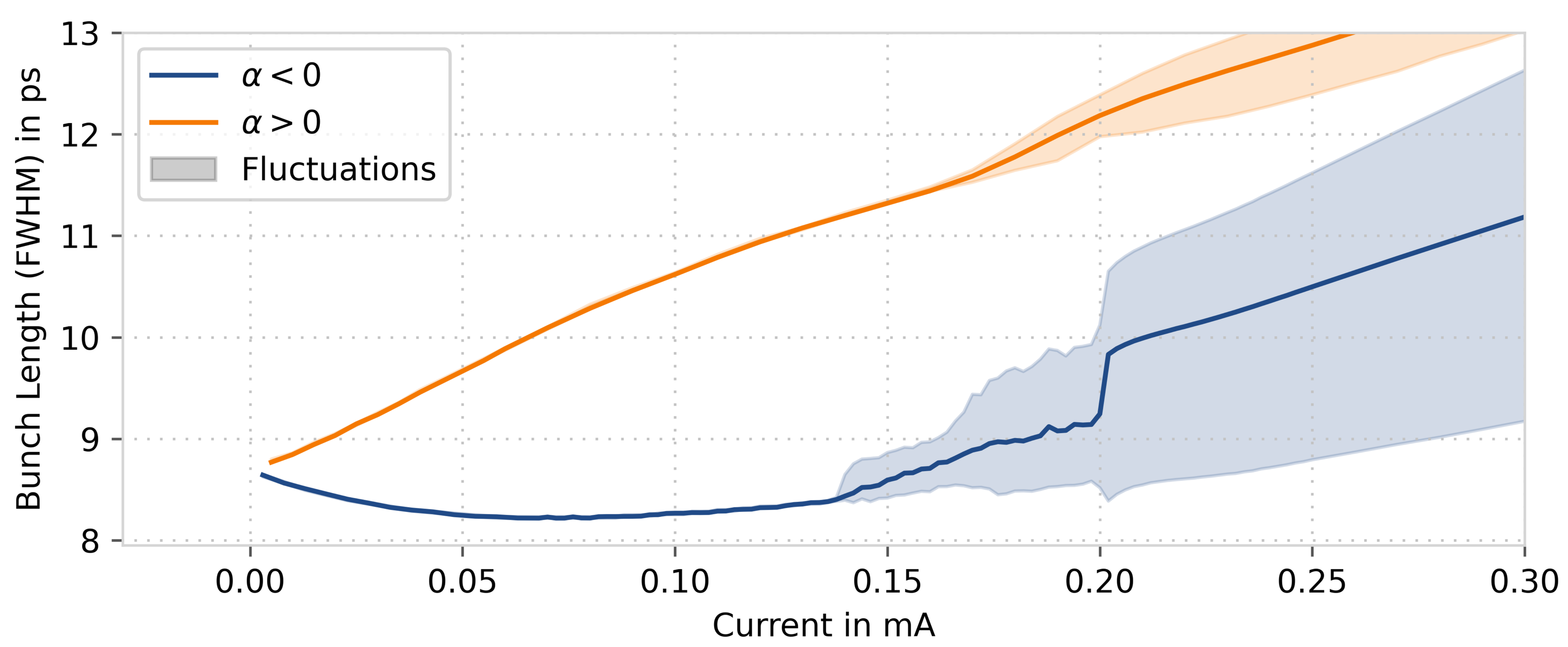
Calculated lattice for a negative value of $\alpha_c = -4\times10^{-4}$ at 1.3 GeV. In large parts the dispersion is negative.

Status of Operation

- Injection into different optics with negative values of α_c has been established at 0.5 GeV [1]
- Maximum beam and bunch current is limited, highest achieved current is 22 mA distributed over 120 bunches and 1 mA for single-bunch operation at 0.5 GeV
- High orbit deviations seem to be beneficial for the injection
- Reduced sextupole strengths and therefore reduced chromaticities seemed beneficial
- Ramping storage ring energy up to 0.9 GeV and 1.3 GeV has been established
- Orbit has been corrected at 0.9 GeV and 1.3 GeV
- Beam lifetime is greatly increased at higher energies

Bunch Length Simulation

- Simulations parameters equivalent to measurements
- Simulations performed with Inovesa [2]
- Purely longitudinal CSR Parallel Plates impedance considered



- Bunch length fluctuations arise at currents where the micro-bunching instability occurs [3]

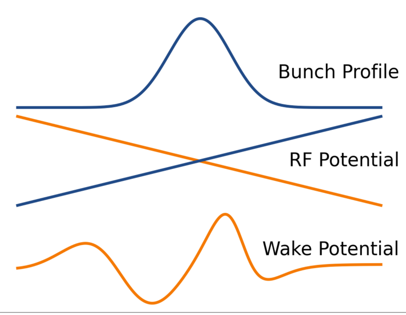
Summary and Outlook

- Optics with negative values of α_c have been successfully established at KARA
- Beam energy can be ramped from 0.5 GeV to 0.9 GeV and 1.3 GeV
- Bunch length σ_z for positive and negative α_c was measured
- At low currents σ_z increases with current for positive and decreases for negative α_c
- Simulations show lengthening for negative α_c at higher currents due to bunch deformations
- Offset in σ_z between positive and negative α_c suggested
- Overall measurement fits expectations
- Next step: Measurements of bunch length up to higher currents at negative α_c
- Further steps: Systematic measurements at different values of α_c

Current-Dependent Bunch Lengthening

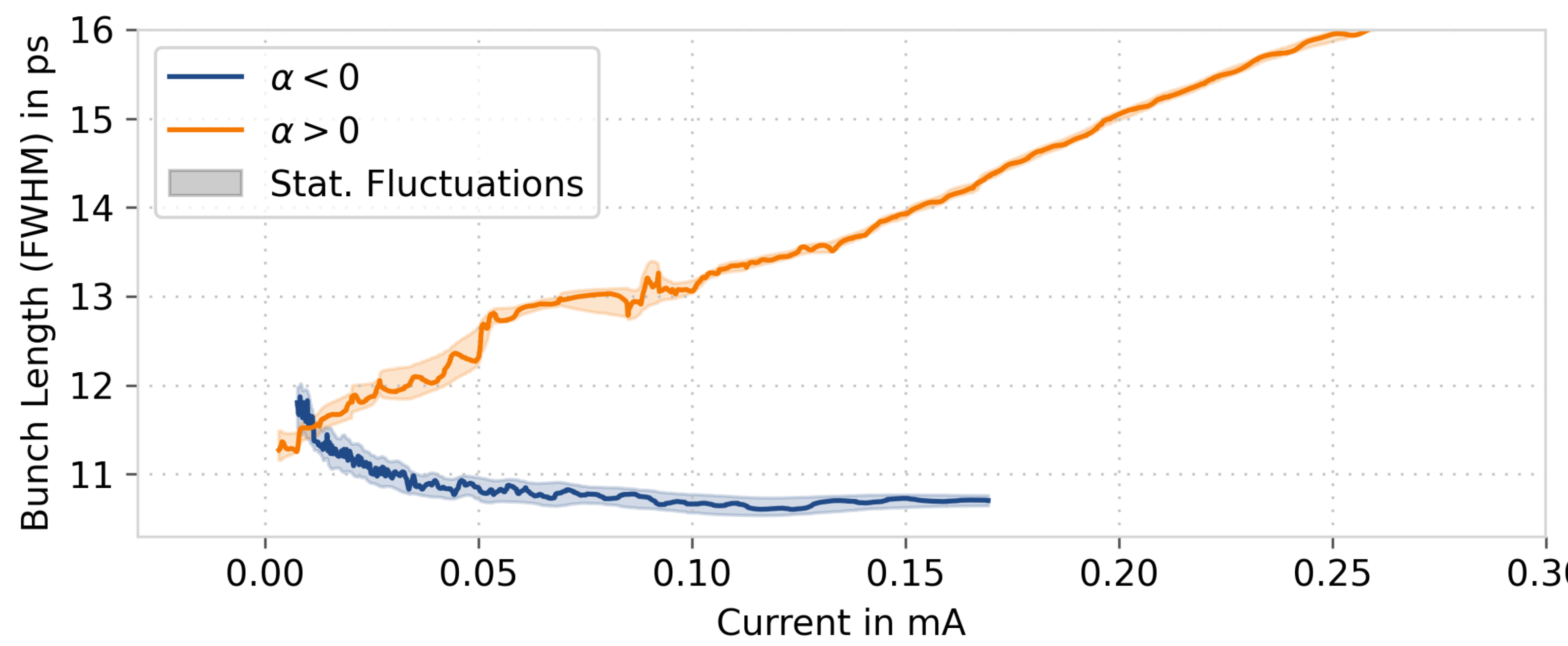
- Bunch length influenced by effective longitudinal potential V_{eff}
- V_{eff} is sum of RF potential and longitudinal wake potential
- Wake potential derived from bunch shape and impedance
- RF potential reversed for $\alpha_c < 0$ operation

⇒ Difference in current-dependent bunch length expected



Bunch Length Measurements

- Bunch length measured using a streak camera setup [4, 5]
- Current decreased naturally during measurement
- Measurement during single bunch 1.3 GeV operation



- Note: Bunch current was limited during measurements

Comparison

- Bunch lengthening with current for positive α_c and shortening for low currents at negative α_c
- Simulations show roughly the same zero current bunch length in both cases as expected
- Measured σ_z at low currents suggests offset between positive α_c and negative α_c
- Roughly gaussian bunches at low currents result in expected shortening for negative α_c
- Simulations show bunch deformations at higher currents resulting in bunch lenghening for negative α_c, not clearly visible in measurements due to limited measurement range

[1] P. Schreiber et al., Status of Operation With Negative Momentum Compaction at KARA, IPAC19, 2019, DOI: 10.18429/JACoW-IPAC2019-MOPTS017
[2] P. Schönfeldt et al., Inovesa/Inovesa: Gamma Three DOI: 10.5281/zenodo.2653504
[3] K. L. F. Bane, Y. Cai, and G. Stupakov, Threshold studies of the microwave instability in electron storage rings, PhysRevSTAB, 2010, DOI: 10.1103/ PhysRevSTAB.13.104402
[4] P. Schönfeldt et al., Fluctuation of Bunch Length in Bursting CSR: Measurement and Simulation, IPAC14, 2014, DOI: 10.18429/JACoW-IPAC2014-MOPRO068
[5] B. Kehrer et al., Visible Light Diagnostics at the ANKA Storage Ring, IPAC15, 2015, DOI: 10.18429/JACoW-IPAC2015-MOPHA037

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