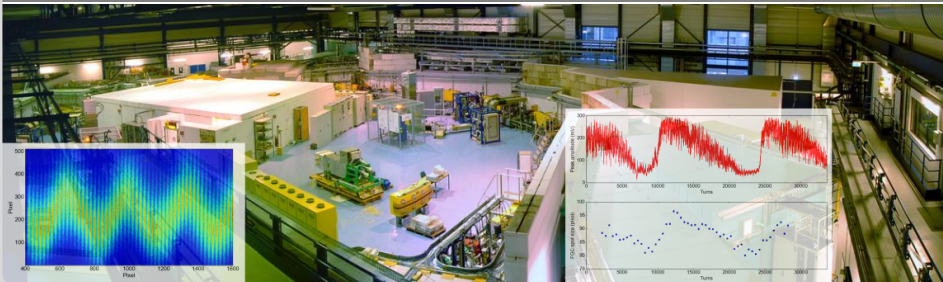


Time-resolved energy spread studies at the ANKA storage ring

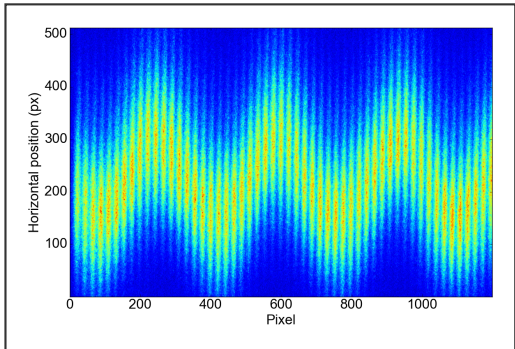
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Time-resolved energy spread studies at the ANKA storage ring

- Energy spread from hor. bunch size
→ Fast-gated intensified camera (FGC)



Time-resolved energy spread studies at the ANKA storage ring

Benjamin Kehrer¹, E. Blomley, M. Brosi, E. Brüderrmann, M. J. Nasse, J. L. Steinmann, P. Schönfeldt, M. Schuh and A.-S. Müller, KIT, Karlsruhe, Germany
¹ benjamin.kehrer@kit.edu

Motivation

Low- γ mode

- Reduce momentum compaction factor
- Bunch length reduced
- More-bunching instabilities → Emission of Coherent Synchrotron Radiation

Energy spread at micro-bunching instabilities

- Energy spread above bunching threshold → Increases with bunch current [1]
- Energy spread and microwave radiation → Same modulation period [2]
- Optimization: Bunch length and CSR → Same modulation period [3]

Systematic studies of low- γ operation

Long time scales

I_e : 4.9 nA, V_{gr} : 1500 kV, I_{gr} : 0.25 mA
 α_e : 1.96 · 10⁻⁴

- Energy spread with same modulation pattern as CSR [3]
- CSR increases when energy spread still decreasing
- Onset of off-axis burst when energy spread reaches lower limit

Short time scales

I_e : 13.85 nA, V_{gr} : 1500 kV, I_{gr} : 1.57 mA
 α_e : 7.21 · 10⁻⁴

- More detailed studies: 24 turns gate separation → 600 ns time range
- CSR starts to increase, energy spread still decreasing → sub-structure
- Sub-structures too small to increase bunch size
- Energy spread blown up at onset of burst [2]

Short bunch-length bunching

I_e : 4.9 nA, V_{gr} : 1500 kV
 α_e : 3.91 · 10⁻⁴

- Average horizontal bunch size (measure for energy spread) for lowest current energy
- For α_e : 2.44 · 10⁻⁴ [6] weak instability [6] (short bunch-length bunching observed at ANKA)
- Energy spread and bunching strength increase again [7]

Fast-gated intensified camera (FGC)

- Camera + galvanometer mirror (G) → scans bunch image over sensor
- Single turn resolution
- Up to 65 spots on CCD
- Energy in 8 bins (μ = 4, σ = 14)
- Pi 2D Gaussian fit
- Spot position
- Spot size

Schottky diodes + DAQ

- Detection: Schottky barrier diodes
- Room temperature
- Response time: < 200 ps
- Bandwidth (50 GHz up to 1 THz)
- On and off-band diodes
- Commercially available (ACST, VDI)
- DAQ: KAPTLING
- Web-based distributed DAQ system [9]
- ADC with turn-by-turn and bunch-by-bunch capability (sampling with fixed phase)
- Continuous streaming (~ 30 GB/s)
- CSR intensity for every bunch and turn

Outlook

- Web interface of FGC: Limited number of data points
- Using a KAPTLING system: 256 pixel line array for turn-by-turn imaging
- Combine with longitudinal bunch profile measurements using Electro-Optical Spectral Diagnostics

Acknowledgements

This work has been supported by the Initiative and Networking Fund of the Helmholtz Association under contract number VH-NG-030 and by the BMBWF under contract numbers GK 12VVA and GK 14VKA.

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Time-resolved energy spread studies at the ANKA storage ring

- Energy spread from hor. bunch size
→ Fast-gated intensified camera (FGC)
- Synchronized with CSR measurements

Time-resolved energy spread studies at the ANKA storage ring

Benjamin Kehrer¹, E. Blomley, M. Brosi, E. Bründemann, M. J. Nasse, J. L. Steinmann, P. Schönfeldt, M. Schuch and A.-S. Müller, KIT, Karlsruhe, Germany
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Motivation

- Low- γ mode
 - Reduce minimum compactron factor
 - Bunch length reduced
 - More-bunching instabilities → Onset of Coherent Synchrotron Radiation
- Energy spread at micro-bunching instabilities
 - Energy spread above bunching threshold → Increases with bunch current [1]
 - Energy spread and microwave radiation → Same modulation period [2]
 - Optimization: Bunch length and CSR → Same modulation period [3]

Systematic studies of low- γ operation

Long time scales	Short time scales	Short bunch-length bunching
I_e : 4.9 nA, V_{RF} : 1500 kV, I_{beam} : 0.25 mA γ_e : 1.96 · 10 ⁴	I_e : 13.55 nA, V_{RF} : 1500 kV, I_{beam} : 1.57 mA γ_e : 2.15 · 10 ⁴	I_e : 4.9 nA, V_{RF} : 1500 kV γ_e : 1.96 · 10 ⁴
<ul style="list-style-type: none"> Energy spread with same modulation pattern as CSR [7] CSR increases when energy spread still decreasing Onset of head-bunch when energy spread reaches lower limit 	<ul style="list-style-type: none"> More detailed studies: 24 turn gate separation → 600 ns time range CSR starts to increase, energy spread still decreasing → sub-structure Sub-structures too small to increase bunch size Energy spread blown up at onset of burst [7] 	<ul style="list-style-type: none"> Average horizontal bunch size (measure for energy spread) for lowest current energy For $\gamma_e < 2.44 \cdot 10^4$ [6] weak instability [6] (start bunch-length bunching observed at ANKA) Energy spread and bunching strength increase again [7]

Fast-gated intensified camera (FGC)

- Camera + gaseous-micrometric mirror (4.5) → sweep bunch image over sensor
- Single turn-resolution
- Up to 65 spots on CCD
- Energy γ -turn ($\gamma > 6$, $N_{turn} < 16$)
- F1: 2D Gaussians
 - Spot position
 - Spot size

Schottky diodes + DAQ

- Detectors: Schottky barrier diodes
- Room temperature
- Response time < 200 ps
- Bandwidth (50 GHz up to 1 THz) and narrowband detectors
- Commercially available (ACST, VDI)
- DAQ: KAPTLING
 - Web-based distributed DAQ system [9]
 - ADC with turn-by-turn and bunch-by-bunch capability (sampling with fixed phase)
 - Continuous streaming (~ 30 GB/s)

→ CSR intensity for every bunch and turn

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[1] H. Behn, K. Oide, M. Zobov, SLAC-PUB-11087 (2005)
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Outlook

- Methods of FGC: Limited number of data points
- Using a KALYPSO system: 256 pixel line array for turn-by-turn imaging
- Combine with longitudinal bunch profile measurements using Electro-Optical Spectral Diagnostics

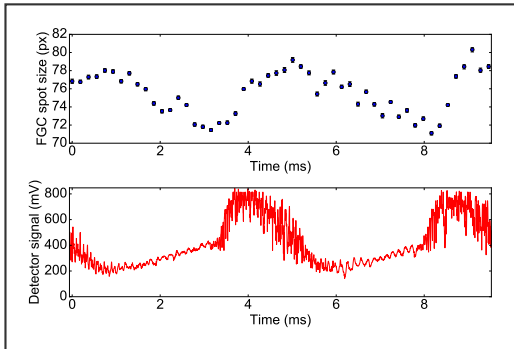
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Time-resolved energy spread studies at the ANKA storage ring

- Energy spread from hor. bunch size
→ Fast-gated intensified camera (FGC)
- Synchronized with CSR measurements
- Long time scales



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Time-resolved energy spread studies at the ANKA storage ring

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Motivation

- Low- γ mode
 - Reduce minimum compactor factor
 - Bunch length studied
 - More bunching instabilities → Emission of Coherent Synchrotron Radiation
- Energy spread at micro-bunching instabilities
 - Energy spread above bunching threshold → Increases with bunch current [1]
 - Energy spread and microwave radiation → Same modulation period [2]
 - Optimization: Bunch length and CSR → Same modulation period [3]

Systematic studies of low- γ operation

Long time scales	Short time scales	Short bunch-length bunching
<ul style="list-style-type: none"> Energy spread with same modulation pattern as CSR [7] CSR increases when energy spread still increasing Onset of next burst when energy spread reaches lower limit 	<ul style="list-style-type: none"> More detailed studies: 24 turn gate separation → 600 ns time range CSR starts to increase, energy spread still increasing → sub-structure Sub-structures too small to increase bunch size Energy spread down up at onset of burst [7] 	<ul style="list-style-type: none"> Average horizontal bunch size (measure for energy spread) for lowest current shot For $I_e \approx 2.44 \cdot 10^{-8}$ A weak instability [6] (short bunch-length bunching) observed at ANKA Energy spread and bunching strength increase again [7]

Fast-gated intensified camera (FGC)

- Camera + gaseous-microarray (A. S.) → sweep bunch image over sensor
- Single turn-resolution w/ CCD
- Up to 65 spots
- Energy in 8 turn ($\beta = 6$, $\text{NOM} = 1 + 16$)
- Pz 2D Gaussians
- Spot position
- Spot size

Schottky diodes + DAQ

- Detection: Schottky barrier diodes
- Room temperature
- Response time < 200 ps
- Bandwidth (50 GHz up to 1 THz)
- Commercially available (ACST, VDI)

DAQ: KAPLUS

- Web-based distributed DAQ system [8]
- ADC with turn-by-turn and bunch-by-bunch capability (sampling with dead phase)
- Continuous streaming (~ 30 GB/s)
- CSR intensity for every bunch and turn

References

[1] H. Behn, K. Ota, M. Zoloto, SLAC-PUB-11087 (2005)
 [2] U. Asp et al., Phys. Rev. ST Accel. Beams, 4, 054011 (2001)
 [3] R. Warrick et al., Nucl. Instrum. Meth. A541, 186 (2006)
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Outlook

- Web-matrix of FGC: Limited number of data points
- Using a KALYPSO system: 256 pixel line array for turn-by-turn imaging
- Combine with longitudinal bunch profile measurements using Electro-Optical Spectral Diagnostics

Acknowledgements

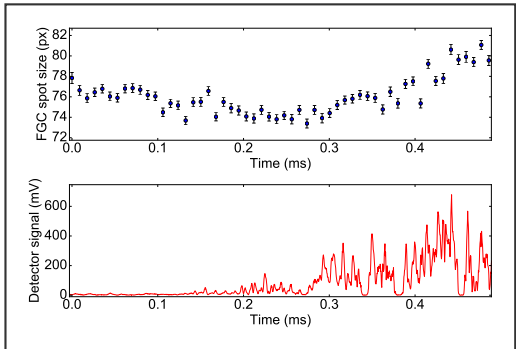
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Time-resolved energy spread studies at the ANKA storage ring

- Energy spread from hor. bunch size
→ Fast-gated intensified camera (FGC)
- Synchronized with CSR measurements
- Short time scales



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Time-resolved energy spread studies at the ANKA storage ring

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¹ benjamin.kehrer@kit.edu

Motivation

- Low- γ mode
 - Reduce minimum impact factor
 - Bunch length reduced
 - More bunching instabilities → Emission of Coherent Synchrotron Radiation
- Energy spread at micro-bunching instabilities
 - Energy spread above bunching threshold → Increases with bunch current [1]
 - Energy spread and microwave radiation → Same modulation period [2]
 - Optimization: Bunch length and CSR → Same modulation period [3]

Systematic studies of low- γ operation

Long time scales	Short time scales	Short bunch-length bunching
<ul style="list-style-type: none"> Energy spread with same modulation pattern as CSR [7] CSR increases when energy spread still decreasing Onset of head-tail bunch when energy spread reaches lower limit 	<ul style="list-style-type: none"> More detailed studies: 24 turn gate separation → 600 ns time range CSR starts to increase, energy spread still decreasing → sub-structure Sub-structures too small to increase bunch size Energy spread drops up at onset of burst [7] 	<ul style="list-style-type: none"> Average horizontal bunch size (measure for energy spread) for beam current 2000 For $\alpha_c = 2.44 \cdot 10^{-4}$ [6] weak instability [6] (start bunch-length bunching observed at ANKA) Energy spread and bunching strength increase again [7]

Fast-gated intensified camera (FGC)

- Camera + galvanometric mirror (A, S) → sweep bunch image over sensor
- Single turn resolution
- Up to 65 spots on CCD
- Gate in 6 turn ($\mu = 6$, $N_{\text{turn}} = 5, 16$)
- PI 2D Galvanometers
 - Spot position
 - Spot size

Schottky diodes + DAQ

- Detection: Schottky barrier diodes
- Rout temperature
- Response time < 200 ps
- Bandwidth (50 GHz up to 1 THz)
- On and narrowband detectors
- Commercially available (ACST, VDI)

DAQ: KAPTLUG

- Web-based distributed DAQ system [8]
- ADC with turn-by-turn and bunch-by-bunch capability (sampling with dead phases)
- Continuous streaming (~ 30 GB/s)
- CSR intensity for every bunch and turn

References

[1] R. Baier, K. Oide, M. Zobov, SLAC-PUB-11087 (2001)
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Outlook

- Full reach of FGC: Limited number of data points
- Using a KALYPSO system: 256 pixel line array for turn-by-turn imaging
- Combine with longitudinal bunch profile measurements using Electro-Optical Spectral Diagnostics

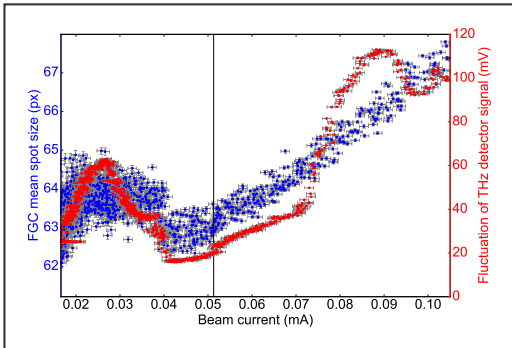
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Time-resolved energy spread studies at the ANKA storage ring

- Energy spread from hor. bunch size
→ Fast-gated intensified camera (FGC)
- Synchronized with CSR measurements
- Short bunch-length bursting



Time-resolved energy spread studies at the ANKA storage ring

Benjamin Kehrer¹, E. Blomley, M. Brosi, E. Bründemann, M. J. Nasse, J. L. Steinmann, P. Schönfeldt, M. Schuh and A.-S. Müller, KIT, Karlsruhe, Germany
¹ benjamin.kehrer@kit.edu

Motivation

Low- γ mode

- Reduce minimum impact factor
- Bunch length spread
- More bunching instabilities → Emission of Coherent Synchrotron Radiation

Energy spread at micro-bunching instabilities

- Energy spread above bunching threshold → Increases with bunch current [1]
- Energy spread and microwave radiation → Same modulation period [2]
- Optimization: Bunch length and CSR → Same modulation period [3]

Systematic studies of low- γ operation

Long time scales

$I_e = 4.8 \text{ kA}$, $V_{RF} = 1500 \text{ kV}$, $I_{beam} = 0.25 \text{ mA}$
 $\sigma_x = 1.36 \cdot 10^{-4}$

- Energy spread with same modulation pattern as CSR [7]
- CSR increase when energy spread still decreasing
- Onset of next burst when energy spread reaches lower limit

Short time scales

$I_e = 13.8 \text{ kA}$, $V_{RF} = 1500 \text{ kV}$, $I_{beam} = 1.67 \text{ mA}$
 $\sigma_x = 2.14 \cdot 10^{-4}$

- More detailed studies: 24 turn gate separation
- CSR starts to increase, energy spread still decreasing → sub-structure
- Sub-structures too small to increase bunch size
- Energy spread down up at onset of burst [7]

Short bunch-length bursting

$I_e = 4.8 \text{ kA}$, $V_{RF} = 1500 \text{ kV}$
 $\sigma_x = 1.36 \cdot 10^{-4}$

- Average horizontal bunch size (measure for energy spread) for lowest current stored
- For $I_e = 2.44 \cdot 10^{-4}$ weak instability [6] (short bunch-length bursting) observed at ANKA
- Energy spread and bunching strength increase again [7]

Fast-gated intensified camera (FGC)

- Camera + galvanometric mirror [4, 5] → sweep bunch image over aperture
- Single turn resolution
- Up to 65 spots on CCD
- Energy in turn ($\mu = 4$, $N_{e^-} = 1 \cdot 10^6$)
- PI 2D GaAs tubes
- Apert position
- Apert lock

Schottky diodes + DAQ

- Detectors: Schottky barrier diodes
- Room temperature
- Response time < 200 ps
- Shield (50 GHz up to 1 THz) and narrowband detectors
- Commercially available (ACST, VDI)
- DAQ: KAPLUS
- With-house developed DAQ system [9]
- ADC with turn-by-turn and bunch-by-bunch capability (sampling with dead phase)
- Continuous streaming (~ 30 GB/s)
- CSR intensity for every bunch and turn

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[1] R. Behn, A. Dier, M. Zoloto, SLAC-PUB-11087 (2005)
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Outlook

- Full match of FGC limited number of data points
- Using a KAPLUS system: 256 pixel line array for turn-by-turn imaging
- Combine with longitudinal bunch profile measurements using Electro-Optical Spectral Diagnostics

Acknowledgements

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