DELTA
The Dortmund 1.5 GeV Synchrotron Radiation Light Source

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DELTA – The Dortmund 1.5 GeV Synchrotron Radiation Light Source

Content:
• Synchrotron Radiation
• Accelerator
• Insertion Devices
• Beam Operation
• Orbit Control
• EU-Cavity Beam Test
• Instability Investigation
• Machine Optics
• Frequent Injection Mode
DELTA - The Dortmund 1.5 GeV Synchrotron Radiation Light Source

L = 115.2 m
E = 1.5 GeV
Electrons with relativistic velocities + transverse acceleration

Broad band spectrum radiation with high directivity

Visible part of synchrotron radiation
\[ \beta = \frac{v}{c} = 0.999999942 \quad @ \; 1.5 \; GeV \]

\[ \gamma = \frac{E_{\text{total}}}{E_{\text{restmass}}} \approx \frac{E_{\text{kin}}}{m_0 c^2} = \frac{1.5 \; GeV}{511 \; keV} \approx 3000 \]

\[ \alpha \approx \frac{1}{\gamma} = \frac{1}{3000} \text{rad} \]

\[ \approx 0.3 \; mrad \]
Radiation Spectrum

\[ \lambda = \frac{c}{v} \quad \text{and} \quad c = 3 \cdot 10^8 \, \frac{\text{m}}{\text{s}} \]

object size \sim \text{wavelength}
tiny, intense and precisely characterised beam

beam current = 120 mA
E = 1.5 GeV
radiated power of beam ~ 20 kW
$P_{\text{sol}} = 63 \text{ MW/m}^2$

$P_{\text{peak}} \approx 8000 \text{ MW/m}^2$
Modern Synchrotron Radiation Devices (Insertion Devices)

- magnet period
- elektron beam
- magnet poles

coherent radiation at resonant wavelength
where we are today in terms of brilliance
general properties of synchrotron radiation

- wiggler / undulators
- dipoles
- small divergence
- polarised
- exactly calculable
- pulsed ~ps
- high intensity
- broad / continuous spectrum
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Dortmunder Elektronen-Speicherring-Anlage

output energy = 75-80 MeV  
total length = 6.4 m  
(E = 12.5 MV/m)  
old SBTF-structure from DESY, Hamburg

thermic electron gun
50 keV, 2 A
single bunch mode
few bunch mode

3 GHz - klystron

Linear Injector

40 MW loss power
(ohmic losses in copper)
4 µsec RF-pulses
@ a few Hertz repetition rate

Full energy booster BoDo

full energy 1.5 GeV ramped storage ring
~ 0.1 Hz rep. rate
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Dortmunder Elektronen-Speicherring-Anlage

- RF-transmitter
  - 500 MHz
  - TV-klystron
  - 30 kW

- DESY-3-cell resonator
  - 500 MHz

- Booster-RF-System

- circulator with RF-load
magnet lattice of storage ring
Single cell cavity
@ DELTA

400 kV @ 500 MHz
RF-power 50 kW cw
loss power cavity 30 kW
energy transfer to beam 20 kW
RF transmitter
500 MHz
TV-klystron
$P_{\text{max}} = 55 \text{ kW}$

cavity behind wall

circulator with glycol-water-RF-load
accelerator control room
## Machine Parameters DELTA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>maximum beam energy</strong></td>
<td>1.5 GeV</td>
</tr>
<tr>
<td><strong>circumference</strong></td>
<td>115.2 m</td>
</tr>
<tr>
<td><strong>nominal beam current</strong></td>
<td>130 mA multi bunch @ 1.5 GeV; 25 mA single bunch @ 550 MeV</td>
</tr>
<tr>
<td><strong>beam lifetime</strong></td>
<td>&gt; 8 h multi bunch @ 1.5 GeV; &gt; 20 min single bunch @ 542 MeV</td>
</tr>
<tr>
<td><strong>horizontal emittance</strong></td>
<td>16 nm rad @ 1.5 GeV</td>
</tr>
<tr>
<td><strong>coupling</strong></td>
<td>3 %</td>
</tr>
</tbody>
</table>
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Dortmunder Elektronen-Speicherring-Anlage

Storage ring operation

I=130mA

12h beam lifetime

8 Ah integrated current

Annual operation 3000 h
Insertion devices @ DELTA

U55 permanent magnet undulator
ACCEL Instruments

SAW superconducting 5.3 T asymmetric multipole wiggler
ACCEL Instruments

U250 electromagnetic undulator
in house fabrication, also acting as FEL undulator
### Superconducting 5.3 T asymmetric multipole wiggler @ DELTA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dipole</th>
<th>Wiggler (sym. mode)</th>
<th>Wiggler (asym. mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field [T]</td>
<td>1.51</td>
<td>2.79</td>
<td>5.30</td>
</tr>
<tr>
<td>Critical current [A] @ 5T and 4.2 K</td>
<td></td>
<td></td>
<td>471</td>
</tr>
<tr>
<td>Number of periods</td>
<td></td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Beam stay clear [mm]</td>
<td>40</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Horizontal opening angle $\theta$ of radiation [mrad]</td>
<td>± 13</td>
<td>± 25</td>
<td></td>
</tr>
<tr>
<td>Critical energy $\varepsilon_C$ [keV]</td>
<td>2.26</td>
<td>4.18</td>
<td>7.93</td>
</tr>
<tr>
<td>Critical wavelength $\lambda_C$ [Å]</td>
<td>5.49</td>
<td>2.97</td>
<td>1.56</td>
</tr>
<tr>
<td>Power P [W/mrad]</td>
<td>4.30</td>
<td>166.89</td>
<td>317.04</td>
</tr>
<tr>
<td>Vertical integrated photon flux @ $\varepsilon_C$ [photons/s/mrad/0.1%BW]</td>
<td>$4.61 \cdot 10^{12}$</td>
<td>$6.86 \cdot 10^{13}$</td>
<td>$2.16 \cdot 10^{13}$</td>
</tr>
<tr>
<td>Type of radiation (off-plane)</td>
<td>elliptical polarised</td>
<td>linear polarised high intensity</td>
<td>great fraction of circular polarisation at high intensity</td>
</tr>
<tr>
<td>Liquid He consumption</td>
<td></td>
<td></td>
<td>~ 12 liters/day with beam</td>
</tr>
</tbody>
</table>

Serving 3 hard-X-ray beamlines

First superconducting multipole wiggler worldwide
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- BL12: Methods (II): Soft X-Rays
  - Photoemission
  - Photoelectron Spectroscopy
  - Fermi-Surface Mapping

L = 115.2 m
E = 1.5 GeV
## SR-Beamlines @ DELTA

<table>
<thead>
<tr>
<th>Beamline</th>
<th>Experiments</th>
<th>Photon energy</th>
<th>Present status</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL 2 / dipole</td>
<td>X-ray fluorescence spectroscopy</td>
<td>white beam</td>
<td>user operation</td>
</tr>
<tr>
<td>(ISAS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL 5 / U250</td>
<td>photoemission, spectroscopy</td>
<td>5 - 400 eV</td>
<td>user operation</td>
</tr>
<tr>
<td>(FZ Jülich)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL 8 / SAW 3</td>
<td>material science, EXAFS, diffraction</td>
<td>2 - 30 keV</td>
<td>under commissioning operational end 2006</td>
</tr>
<tr>
<td>(U Wuppertal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL 9 / SAW 2</td>
<td>grazing incidence X-ray diffraction, SAXS, XSW, inelastic X-ray scattering</td>
<td>4 - 30 keV</td>
<td>user operation</td>
</tr>
<tr>
<td>(U Dortmund)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL 10 / SAW 1</td>
<td>EXAFS</td>
<td>4 - 30 keV</td>
<td>under construction operational 2007</td>
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<tr>
<td>(U NRW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL 11 / U55</td>
<td>photoemission spectroscopy, photoelectron diffraction</td>
<td>55 - 1500 eV</td>
<td>user operation</td>
</tr>
<tr>
<td>(U Dortmund)</td>
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</tr>
<tr>
<td>BL 12 / dipole</td>
<td>valence band spectroscopy, Fermi-surface mapping</td>
<td>6 – 200 eV</td>
<td>under commissioning operational end 2006</td>
</tr>
<tr>
<td>(U Dortmund)</td>
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<td></td>
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</tr>
</tbody>
</table>

**Wiggler Beamlines**
Operation
30 weeks (3000 h)
2000 h user operation.
1000 hours machine optimisation
and machine physics

Performance 2004/2005:
Average availability during 20 user weeks 94/89 %.
Max. beam current 120 mA.
Average lifetime ~ 7hrs

Performance 2006:
availability 90%
Max. beam current 130 mA.
Average lifetime ~ 8-10 hrs

User operation

Availability during user weeks 2005

only minor
vacuum openings
Mean time between failure 2003 - 2005

<table>
<thead>
<tr>
<th>Nutzerwoche</th>
<th>Zeit zwischen zwei Fehlern [hrs]</th>
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<tbody>
<tr>
<td>1-5</td>
<td>0</td>
</tr>
<tr>
<td>6-10</td>
<td>5</td>
</tr>
<tr>
<td>11-15</td>
<td>10</td>
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<td>16-20</td>
<td>15</td>
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<td>21-25</td>
<td>20</td>
</tr>
<tr>
<td>26-30</td>
<td>25</td>
</tr>
<tr>
<td>31-35</td>
<td>30</td>
</tr>
<tr>
<td>36-40</td>
<td>35</td>
</tr>
<tr>
<td>41-45</td>
<td>40</td>
</tr>
<tr>
<td>46-50</td>
<td>45</td>
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</table>

- MTBF 2004 = 24 hrs
- MTBF 2005 = 21 hrs

Acceptable, but there’s room for improvement
Orbit Control and Stability

Beam Position Monitor BPM

Difference Signal:

\[ U_{\Delta x} = a \frac{(I_2 + I_3) - (I_1 + I_4)}{\sum_{j=1}^{4} I_j} \]

Sum Signal:

\[ U_{\sum} = a \cdot (I_1 + I_2 + I_3 + I_4) \]
Orbit Control and Stability

slow (0.1 – 1 Hz) global orbit feedback system

method:
- singular value decomposition based on a measured orbit response matrix

\[
\begin{bmatrix}
\vec{r}_1 & \vec{r}_2 & \vec{r}_3 & \cdots & \vec{r}_n
\end{bmatrix}
= R_{ij}
\]

54 BPMs
30 correctors

Orbit Stability

M. Grewe, thesis, Univ. Dortmund 2005
Orbit Stability

- limited number of BPMs and correctors
- limited corrector strengths
- beam current (heat load) induced movement of vacuum chambers and quadrupols
- ongoing program concerning machine surveillance and magnet repositioning and......
- ..... decoupling of quadrupoles and vacuum chambers (BPMs)
- nevertheless: reference orbit is reproducible over months within +/- 250 μm horizontally and +/- 150 μm vertically
Fast Beam and Instability Investigation

- filling pattern measurement bunch by bunch, turn by turn
- postmortem analysis of beam loss due to coupled bunch mode - CBM – instabilities
- real time longitudinal CBM instability detection
Set up

Acqiris DP214
- 2Gs/s sampling rate
- 8 Bit resolution
- 1Ghz bandwidth

Bunch by Bunch Beam Analysis

- sampling of BPM sum signal at 2 GS/s, bandwidth 1 GHz
- oversampling technique using shift between RF frequency and sampling frequency
real time (~ 1 s delay) analysis of longitudinal coupled bunch CBM modes

I > 95 mA

I < 90 mA

Coupled Bunch Mode No. 1 - 192

filling pattern + option to inject beam into specific buckets

FFT of phase modulated signal (appr. 700 revolutions)

real time (~ 1 s delay)
CBM Investigations @ DELTA
DORIS type cavity

$E = 1.5 \text{ GeV}$

$I_{th} \approx 75 \text{mA}$

$I_{th} \approx 35 \text{mA}$

$T = 40-60 \degree \text{C}$

$I = 87 \text{mA}$
CBM Investigations @ DELTA
DORIS type cavity with damping antennas

Threshold CBM 22
Threshold CBM 52

E = 1.5 GeV

Oscillation Amplitude (degree)

Coupled Bunch Mode No. 1 - 192
EU-Project:
Design, Construction and Beam Test of a n.c. HOM-damped 500 MHz-Resonator for Synchrotron Radiation Sources

Alu-model
The HOM-Damped EU-Cavity

- Single Trapped Mode Resonator
- Plunger
- Nose cones
- Ridged waveguides
- RF window

- Waveguide cut-off between fundamental and first HOM frequency
- HOM energy is dissipated in external RF loads

Cavity design: F. Marhauser & E. Weihreter, BESSY, Berlin
Residual Longitudinal Impedance

\[ Z_{\parallel} < 5 \text{ k}\Omega \]

- complex time domain calculations for a very complex geometry
- full validation of calculations by bead-pull measurements (o)
- effective damping also of transverse \( Z \)

\( o = \text{measured data} \)
Characteristics of Damped HOMs

Damping of a HOM decreases its $Q$ and $R_S$

⇒ Resonance becomes broader (real part)

⇒ Probability to hit it with a harmonic increases

⇒ Temperature tuning not necessary

@ low energy one is able to detect even low impedances

\[ R(f) = R_S \left( 1 + Q^2 \left( \frac{f^2 - f_r^2}{f^2 f_r^2} \right)^2 \right)^{-1} \]
Installing the Cavity
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collaboration partners & DELTA-group
EU-cavity in place

CBM Characterisation of EU-Cavity

E= 1.5 GeV

CBM 52-55 not induced by cavity, also seen with the DORIS-type cavity with threshold currents I=85-130 mA

reason still unknown, candidates are:
- strip line kickers
- broken RF-contacts in bellows, valves
- resonant vacuum chambers and tapers

New (2/2007):
Stable operation by shifting the RF-frequency (~500 MHz) by – 5kHz
$$U(\omega) = Z(\omega) I(\omega)$$

HOM-damper signal compared with long. impedance @542 MeV few bunch

20 MHz bandwidth

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• The EU-HOM-damped-prototype has been successfully tested with beam at 1.5 GeV and 524 MeV for more than one year within two periods of time (2004-2006).
• No cavity induced instabilities have been found. Overall experience compared with the DORIS operation is a more stable beam during injection and much higher beam currents at low energy of up to 300 mA @ 542 MeV.
• DELTA exhibits longitudinal CBM above 80-130 mA not EU-cavity induced. Source of impedance (10 – 100 kΩ) not found yet.
• The cavity impedance can be deduced from the HOM-signal (first steps done, no complete understanding however)
Modelling of the Machine Optics

- 2 independent measurements of optical $\beta$-functions.
- tune scan method (local variation of quadrupole strengths and orbit response matrix analysis (ORM)).
- comparable results but at different locations
- ORM-analysis provides sensitive information on phase beating

a big step forward towards a better machine modelling.
Example: Horizontal „Phase Beating“
Phase Advance Deviations between Model and Measurement

![Graph showing phase advance deviations](image)

refined quadrupole strengths and magnet locations

minimisation of $\Delta \Psi$
Frequent Injection @ DELTA

- Increased average beam current
- Increased photon flux for users
- Constant heat load on chambers and beam lines
- Increased machine stability
- Machine tests with shutters closed successful.
- Discussions with users and approval authorities ongoing.

125 mA +/- 5 %

~ 7 h

Constant lifetime


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## Thanks to the Accelerator Group

### an attempt to distribute responsibilities 2006/07

<table>
<thead>
<tr>
<th>Professors:</th>
<th>K. Wille (group head, teaching, machine optics, radiation devices,...)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T. Weis (teaching, RF-systems, beam dynamics, instabilities, diagnostics)</td>
</tr>
<tr>
<td>Staff:</td>
<td>J. Friedl (radiation safety, infrastructure, HV and pulsed elements)</td>
</tr>
<tr>
<td></td>
<td>P. Hartmann (RF-systems, linac, beam diagnostics)</td>
</tr>
<tr>
<td></td>
<td>D. Schirmer (control system, radiation devices)</td>
</tr>
<tr>
<td></td>
<td>G. Schmidt (vacuum, alignment, magnets, beam orbit and control)</td>
</tr>
<tr>
<td></td>
<td>U. Berges (part time, magnets, power supplies)</td>
</tr>
<tr>
<td>PHD students:</td>
<td>C. Böhme (beam diagnostics at COSY, Jülich)</td>
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<tr>
<td></td>
<td>R. Heine (RF-cavity, instabilities, diagnostics) not @ GSI</td>
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<tr>
<td></td>
<td>H. Huck (single bunch and low energy operation, free electron laser FEL)</td>
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<td></td>
<td>O. Kopitetzki (beam orbit measurement and control)</td>
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<tr>
<td></td>
<td>J. Fürsch (fast beam diagnostics, frequency domain techniques)</td>
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<tr>
<td>Diploma students:</td>
<td>R. Burek, F. Rüdiger, F. Nolz</td>
</tr>
<tr>
<td>Technical support:</td>
<td>H. Ruhl + G. Dahlmann (infrastructure, power supplies)</td>
</tr>
<tr>
<td></td>
<td>P. Kortmann + T. Dybiona (mechanical workshop, cryo technique)</td>
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<td></td>
<td>NN + W. Brembt (radio frequency, elektronics)</td>
</tr>
<tr>
<td></td>
<td>A. Erpelding (digital networking, remote control)</td>
</tr>
<tr>
<td></td>
<td>B. Hippert (vacuum system), P. Lindemann (administration, controlling)</td>
</tr>
</tbody>
</table>
Thanks for the attention!