CAS / INTRODUCTION TO ACCELERATOR PHYSICS
Zakopane, Poland, 1-13 October 2006

SYNCHROTRON LIGHT SOURCES

Albin F. Wrulich

- SYNCHROTRON LIGHT-SOURCES
- SYNCHROTRON-LIGHT SOURCES
SYNCHROTRON RADIATION FROM SUPERNova SN2006ke

PRINCIPLES

REQUIREMENTS

FEATURES

OUTLOOK
Accelerated charged particles are emitting electromagnetic radiation. The dominant effect comes from transverse acceleration, as the deflection of a charged particle in a bending magnet of a circular accelerator:

\[ E_e^{\text{after}} = E_e^{\text{before}} - h\nu \]

Due to the emission the energy of the particle is changed!
1898 Liénard:

\[ P = \frac{2}{3} \frac{e^2 \gamma^6}{4 \pi \varepsilon_0 c} \left[ \dot{\beta}^2 - \left( \beta \times \dot{\beta} \right) \right] \]

POWER emitted:

\[ P \sim \frac{\gamma^4}{\rho^2} \]

ENERGY lost per turn:

\[ E = \int_0^{T_o} P \, dt \sim \frac{\gamma^4}{\rho} \]

LONGITUDINAL:
Radiation field cannot separate itself from the Coulomb field

TRANSVERSE:
Radiation field quickly separates itself from the Coulomb field
The POWER of the emitted radiation is increasing with the 4\textsuperscript{th} power of the Lorentz factor!

\[ P \sim \frac{\gamma^4}{\rho^2} \]

Since:

\[ \gamma = 1 + \frac{E_k}{E_o} \approx \frac{E_k}{E_o} = \frac{eU}{E_o} \]

Predominately particles with low masses are suitable for the use in light sources.

**ELECTRONS, POSITRONS**

\[ \beta = \frac{v}{c} = \sqrt{1 - \frac{1}{\gamma^2}} \]

\[ E_o \quad \text{Rest energy} \]

\[ E_k \quad \text{Kinetic energy} \]

\[ U \quad \text{Accelerating voltage} \]
SYNCHROTRON RADIATION FROM A BENDING MAGNET

\[ N_{\gamma} \approx 2.1 \ x^{1/3} \]

\[ \approx 1.3 \ \sqrt{x \ e^{-x}} \]

\[ p = \frac{e^2 c \ \gamma^4}{6\pi \pi_o \ \rho^2} \]

\[ \omega_c = \frac{3 \cdot c \gamma^3}{2 \ \rho} \]

1949 - On the classical radiation of accelerated electrons / J.S. Schwinger
WHAT LIGHT CHARACTERISTIC IS REQUESTED FOR EXPERIMENTS

- HIGH BRILLIANCE
- COHERENCE
  - Transverse coherence
  - Longitudinal coherence
- POLARISATION
- SHORT PULSES

LOTS OF OTHER REQUIREMENTS
as stability, tunability, wide spectral range, higher photon energies
(shorter wavelengths)
HIGH BRILLIANCE

Users want a MANY PHOTONS on the sample!

\[ B \sim \frac{F}{S\Omega} \]
For smaller sample size most of the photons are wasted. They generate an unwanted heating of the optical elements!
To overcome this problem: decrease source size and divergence, i.e. increase the brilliance

\[ B \sim \frac{F}{S\Omega} \]
BRILLIANCE = FIGURE OF MERIT

\[ B = \frac{F}{(4\pi)^2 \left( \sum x \sum y \right) \left( \sum x' \sum y' \right)} \]
\[ \Sigma^2 = \sigma_e^2 + \sigma_\gamma^2 \]

\[ \sigma_e \gg \sigma_\gamma \rightarrow \sum x \sum x' \approx \sigma_x \sigma_x' = \varepsilon_x \]

\[ \rightarrow \text{TRUE FOR MOST PRACTICAL CASES} \]

Here we assumed:

\[ \sigma_x = \sqrt{\varepsilon_x \beta_x} \quad \sigma_x' = \sqrt{\frac{\varepsilon_x}{\beta_x}} \]

\[ \sigma_\gamma = \frac{\sqrt{\lambda L}}{4\pi} \quad \sigma_\gamma' = \sqrt{\frac{\lambda}{L}} \quad \text{IF} \quad \sigma_\gamma \sigma_\gamma' = \frac{\lambda}{4\pi} = \sigma_x \sigma_x' = \varepsilon_x \]

DIFFRACTION LIMIT
HIGH BRILLIANCE is needed for: CRYSTALLOGRAPHY

CRYSTAL  DIFFRACTION PATTERN  RECONSTRUCTION

N. Ban, S. Iwata, U. Baumnan et al.

... to get the maximum flux into the sample acceptance phase space!
COHERENCE

→ is the property that enables a wave to produce visible diffraction and interference effects

A point-like monochromatic source always creates diffraction patterns
LATERAL COHERENCE - is increasing with brilliance

Extended monochromatic source

\[ F_c = \left( \frac{\lambda}{2} \right)^2 \frac{1}{(4\pi)^2} \frac{F}{S\Omega} \sim \left( \frac{\lambda}{2} \right)^2 B \]

\[ S = \left( \frac{d}{2} \right)\pi \]

\[ \Omega = 4\pi \sin^2 \frac{\theta}{4} \approx \frac{\theta^2 \pi}{4} \]

Full lateral coherence exists if \( d \theta = 2\lambda \)
LONGITUDINAL COHERENCE
- needs light emitted in a small bandwidth

UNDULATOR: \[ \frac{\Delta \lambda}{\lambda} = \frac{I}{2N} \]
\[ N \ldots \text{number of magnet poles} \]

\[ \Rightarrow \text{long undulators can be used to increase the longitudinal coherence (suggested for some RECIRCULATOR projects)} \]

Coherent length of a point-like source with \( \Delta \lambda \) bandwidth

\[ L_c = \frac{\lambda}{\Delta \lambda/\lambda} \]

\[ \Rightarrow \text{is the length over which 2 waves with } \Delta \lambda \text{ wavelength difference run 180 deg out of phase!} \]
COHERENCE is needed for ....

EYE OF A FLY

\[ n = 1 - \delta + i\beta \]

PHASE CONTRAST IMAGING
HOLOGRAPHY
SPECKLE INTERFEROMETRY
....

MATERIAL SCIENCE BEAMLINE: Marco Stampanoni, Rafael Abela
\[ \lambda = 0.08 \text{ nm} \]

Contact: only *absorption* contrast

R=100 mm: features of size \( \zeta \sim 3 \mu m \) appear in enhanced *phase* contrast

"edge-enhanced contrast"
RELEVANCE OF COHERENCE for CRYSTALLOGRAPHY

Structure of a molecule (Ribosome)

Diffraction pattern
Problem: phase of the diffraction pattern is unknown!
RELEVANCE OF COHERENCE - *DIFFRACTION PATTERN OF A DUCK*

A (2-dimensional) DUCK

Creates this diffraction pattern (the colors encode the phase)

Curtesy Ischebeck
Images by Kevin Cowtan, Structural Biology Laboratory, University of York
RELEVANCE OF COHERENCE - **DIFFRACTION PATTERN OF A CAT**

A CAT

... and its diffraction pattern

Curtesy Ischebeck
Images by Kevin Cowtan, Structural Biology Laboratory, University of York
RELEVANCE OF COHERENCE - RECONSTRUCTION

Combine the AMPLITUDE of the diffraction pattern OF THE CAT with the PHASE of the diffraction pattern OF THE DUCK →

The result: A DUCK !!

Curtesy Ischebeck
Images by Kevin Cowtan, Structural Biology Laboratory, University of York
**POLARISATION**

Electric vector oscillates in one plane only or rotates as the wave propagates.

POLARISATION is needed for:

**MAGNETIC CIRCULAR DICHROISM**
**TO FIND OUT THE ORIENTATION OF MOLECULES**
Magnetic ripple in as-grown cobalt-Terfenol sandwich film on pre-patterned Si substrate.

G. Schütz, G. Schmahl, P. Fischer
HOW ARE THESE LIGHT FEATURES ACCOMPLISHED BY ACCELERATOR CHARACTERISTICS?
How to get the best performance of the light, i.e. maximum Brilliance

\[ B = \frac{F}{(4\pi)^2 \sum_x \sum_y} = \frac{F}{(4\pi)^2 \varepsilon_x \varepsilon_y} = \frac{F}{(4\pi)^2 \kappa \varepsilon_x^2} \]

The Flux $F$ is proportional to the stored beam current  
\( \kappa \) is the emittance coupling.

In order to get the maximum Brilliance, the emittance must be minimized!

The emittance of an electron storage ring is defined as the phase space area that contains one standard deviation of the gaussian particle distribution

The emittance of an electron storage ring is given by the equilibrium between quantum fluctuation and radiation damping
In an electron storage ring the emittance is a characteristic quantity of the magnet lattice.

In order to minimize it we have to understand how it is generated!

**BASICS 1:**

**BENDING MAGNET**

Particles with different energies are moving on different orbits in a bending magnet → **DISPERSION** orbit!

**Basic equation:**

\[ \frac{1}{\rho} = \frac{e}{p} B \rightarrow \]

\[ \frac{1}{\rho} = \frac{e}{p_0}\left(1 + \frac{\Delta p}{p_0}\right) B \]

\[ \frac{1}{\rho} \approx \frac{e}{p_0}\left(1 - \frac{\Delta p}{p_0}\right) B \]
**BASICS 2:**

If a particle is not on its closed orbit, it performs betatron oscillations around this closed orbit:

\[ x(s) = A \cos[\phi(s) - \phi_o] \]

\[ x'(s) = -A \frac{\alpha}{\beta} \cos[\phi - \phi_o] - A \frac{1}{\beta} \sin[\phi - \phi_o] \]

**CONSTANT OF THE MOTION**

\[ A^2 = \varepsilon \beta = x^2 + (x\alpha + x' \beta)^2 \]

at position ‘s’

OR

\[ \varepsilon = x^2 \gamma + 2xx' \alpha + x^2 \beta \]

everywhere in the ring

\[ \gamma = \frac{1 + \alpha^2}{\beta} \]
An electron emitting a radiation quantum in the bending magnet loses energy and finds itself afterwards not on its closed orbit anymore.

CHANGE IN COORDINATE:

\[ \frac{\Delta E}{E_o} < 0 \]

\[ \Delta x = - \frac{u}{E_o} D_x \]

\[ \Delta x' = - \frac{u}{E_o} D'_x \]

The particle starts to oscillate around the new closed orbit with a betatron amplitude corresponding to the difference in closed orbit before and after the energy jump.

Substitution of these changes into the expression for the constant of motion leads to:

\[ A^2 = \left( x - D \frac{u}{E_o} \right)^2 + \left[ \left( x' - D' \frac{u}{E_o} \right) \alpha + \left( x' - D' \frac{u}{E_o} \right) \beta \right]^2 \]

\[ A^2 = A_o^2 - 2 \frac{u}{E_o} \left[ xD + (x\alpha + x'\beta)(D\alpha + D'\beta) + \left( \frac{\Delta u}{E_o} \right)^2 \left[ D^2 + (D\alpha + D'\beta)^2 \right] \right] \]
Averaging over many turns makes the mid term vanishing and we get:

$$\Delta(A^2) = A^2 - A_o^2 = \frac{u^2}{E_o^2} \left[ D_x^2 + (D_x \alpha_x + D'_x \beta_x)^2 \right]$$

$$H(s)$$

**COURANT SNYDER INVARIANT**

In order to get the beam size, respectively the emittance one has to perform:

→ Statistical averaging over all emissions in one turn
→ Averaging over all betatron phases of the particle motion
→ Equilibration to the radiation damping

$$\varepsilon_x = C_q \frac{\gamma^2}{J_x} \left\langle \frac{H}{\rho^3} \right\rangle$$

For constant radius $\rho$ we get:

$$\varepsilon_x = C_q \frac{\gamma^2}{J_x} \left\langle \frac{H}{\rho} \right\rangle_{BEND}$$
The energy lost in one turn due to synchrotron radiation is substituted by the cavities:

Before emission
\[ x'_o = \frac{p_{ox}}{p_{os}} \]

After emission
\[ x'^* = \frac{p_x^*}{p_s^*} = \frac{p_{ox}}{p_{os}} = x'_o \]
\[ \delta x' = -x'_o \frac{u}{E_o} \]

After cavity passage
\[ x' = \frac{p_x^*}{p_s} = \frac{p_x^*}{p_s + \delta p} \approx x'_o \left( 1 - \frac{\delta p}{p_s} \right) \]
Substituting in the expression for the constant of motion and averaging over all betatron phases leads to (neglecting quadratic terms):

\[ \Delta A^2 = A^2 - A_o^2 = -A^2 \frac{u}{E_o} \rightarrow \frac{\Delta A}{A} = -\frac{1}{2} \frac{u}{E_o} \]

Summation over all energy emissions in one turn:

\[ \sum u_i = U_T \rightarrow \left\langle \frac{\Delta A}{A} \right\rangle = -\frac{1}{2} \frac{U_T}{E_o} \rightarrow \frac{1}{A} \int_0^{\tau_x} dA = \frac{1}{T_o} \left\langle \frac{\Delta A}{A} \right\rangle = \frac{1}{\tau_x} = -\frac{1}{2} \frac{U_T}{E_o T_o} \]
Equilibrium between quantum fluctuation and radiation damping:

\[
\langle \frac{dA^2}{dt} \rangle = \frac{\dot{N}_{ph} \langle u^2 \rangle H}{E_o^2}
\]

Averaging over all emission processes of one turn leads to →

\[
\frac{1}{A} \frac{dA}{dt} = \frac{1}{T_o} \langle \Delta A \rangle = \frac{1}{\tau_x}
\]

Averaging over all betatron phases for the radiation damping →

Equilibrium between quantum fluctuation and radiation damping:

\[
\langle \frac{dA^2}{dt} \rangle = 2 \langle A \frac{dA}{dt} \rangle = 2 \langle A^2 \frac{1}{A} \frac{dA}{dt} \rangle = \frac{2}{\tau_x} \langle A^2 \rangle
\]

\[
\sigma_x^2 = \frac{\langle A^2 \rangle}{2} = \frac{1}{4} \tau_x \frac{\dot{N}_{ph} \langle u^2 \rangle H}{E_o^2} \Rightarrow \epsilon_x = C_q \gamma^2 J_x \frac{\langle H \rangle}{\rho^3}
\]
To get the minimum emittance the integral over the Courant Snyder invariant $H$ over the length of the bending magnets has to be minimized:

$$\langle H(s) \rangle_{\text{BEND}} = \frac{1}{L} \int_{0}^{L} H(s) ds \rightarrow \text{min}.$$ 

**SINGLE MAGNET OPTIMIZATION:**

In a bending magnet the dispersion is developing as:

$$D(s) = \rho (1 - \cos \frac{s}{\rho})$$

$$D'(s) = \sin \frac{s}{\rho}$$

A rectangular magnet corresponds to a drift in the horizontal plane and the optical functions $\alpha, \beta, \gamma$ inside have a simple relations to the initial values at the entrance of the magnet:

$$\beta(s) = \beta_o - 2\alpha_o s + \gamma_o s^2$$

$$\alpha(s) = \alpha_o - \gamma_o s$$

$$\gamma(s) = \gamma_o$$
Substitution of these relations into the expression for the Courant Snyder Invariant (for $D_o = 0$ and $D'_o = 0$) →

\[
D_x^2(s) + \left[D_x(s)\alpha_x(s) + D'_x(s)\beta_x(s)\right]^2
\]

We get a functional dependence on $s$ and coefficients that include the initial parameters $\beta_o$, $\alpha_o$ and the bending radius $\rho$.

After performing the integration we get:

\[
\langle H(s) \rangle = \frac{L^2}{\rho^2} \left[ \frac{1}{3} \beta_o - \frac{1}{4} \alpha_o L + \frac{1}{20} \gamma_o L^2 \right]
\]

To find the minimum we have to solve:

\[
\frac{\partial H}{\partial \beta_o} = 0 \quad \text{leads to:} \quad \beta_o = 2L\sqrt{\frac{3}{5}}
\]

\[
\frac{\partial H}{\partial \alpha_o} = 0 \quad \text{leads to:} \quad \alpha_o = \sqrt{15}
\]

Substituting this values in the expression for the emittance we find for the minimum →
MINIMUM EMITTANCE:

\[ \varepsilon = \frac{C_q \gamma^2}{J_x} K \left( \frac{L}{\rho} \right)^3 = \frac{C_q \gamma^2}{J_x} K \phi_B^3 \]

\[ K = \frac{1}{4\sqrt{15}} \approx 6.5 \cdot 10^{-2} \]

We can now construct a simple achromat structure →

DOUBLE BEND ACHROMAT STRUCTURE

DBA
**PROBLEM with the DBA**

In the center of the achromat we have a symmetry point, i.e. $\beta = \alpha \rightarrow D' = 0$

- Beta function and dispersion must be matched to zero slope in the center by the quadrupole:

**THIS IS NOT POSSIBLE!!**
(with a single Quadrupole)

To reach the theoretical minimum for a DBA lattice at least 2 quadrupoles are needed which are separated by a certain distance:

$d > d_{\text{min}}$
EXAMPLE: \textit{DBA}

OPTICAL FUNCTIONS
With ONE quadrupole in the achromat

MAGNET STRUCTURE
With \textit{>TWO} quadrupoles to approach the theoretical minimum
$$\varepsilon = \frac{C_q \gamma^2}{J_x} K \phi_B^3$$

Horizontal damping partition number!

$$\frac{1}{\tau_x} = -\frac{1}{2J_x} \frac{U_T}{E_0 T_0}$$

The sum of all 3 damping partition numbers is constant, i.e. damping can be transferred from the longitudinal direction to the horizontal direction for a proper chosen magnet structure.

$$J_x + J_y + J_s = 4$$

If focusing and bending are separated in magnet structure – separate function magnet structure – we have:

$$J_x = 1, \quad J_y = 1, \quad J_s = 2$$

With a combined function magnet structure we can have $J_x > 1$ and therefore further reduce the emittance.
EXAMPLE: **ELETTRA**

\[
\varepsilon = \frac{C_q \gamma^2}{J_x} K \phi_B^3 \\
J_x = 1.3
\]

→ adds also vertical focusing and keeps \( \beta_y \) low!
The other structure frequently used is the TRIPLE BEND ACHROMAT TBA.

Now we have a symmetry point in the center of the middle bending magnet, i.e.

\[ \alpha = 0 \]
\[ D'_0 = 0 \]

**CENTER MAGNET OPTIMIZATION (starting from the center):**

\[ \langle H(s) \rangle_{BEND} = \frac{1}{L} \int_{0}^{L} H(s) ds \rightarrow \text{min}. \]

\[ D(s) = D_o + \rho(1 - \cos \frac{s}{\rho}) \]
\[ D'(s) = \sin \frac{s}{\rho} \]
\[ \beta(s) = \beta_o + \frac{s^2}{\beta_o} \]
\[ \alpha(s) = -\frac{s}{\beta_o} \]

\[ \varepsilon_{min} = \frac{C_q \gamma^2}{J_x} K \phi_{BEND}^3 \]
\[ K = \frac{7}{36 \sqrt{15}} \approx 5 \cdot 10^{-2} \]
**PROBLEM (1) with the TBA**

- We have to match now dispersion and beta function from the exit of the optimized outer bending magnet to the center of the optimized inner bending magnet.

**THIS IS NOT POSSIBLE !!** (under no circumstances)

The theoretical minimum of the TBA structure can’t be reached but just approached!

But there is nevertheless a big gain due to the reduction of the bending angle →

\[ \varepsilon_{min} = \frac{C_q \gamma^2}{J_x} K \phi_{BEND}^3 \]

\[ \phi_{TBA} = \frac{2}{3} \phi_{DBA} \]

**NOTE:** if a dispersion in the straight section is permitted the emittance can be further reduced!
PROBLEM (2) with the TBA

\[ \frac{\Delta Q}{\Delta p / p_o} = \xi = \frac{1}{4\pi} \int_C \beta(s)K(s)ds \]

Has to do with the chromaticity correction:

Which is done by introducing sextupoles in the magnet structure.

\[ \begin{align*}
\Delta x' &= m(x^2 - y^2) & m = \frac{1}{2} \frac{B'' L}{B_o \rho} \\
\Delta y' &= -2mxy \\
\Delta x' &= m(\ell \beta + \delta D_x)^2 - y_\beta^2 \\
\Delta y' &= -2m(\ell \beta + \delta D_x)y_\beta
\end{align*} \]

\[ \xi_x = \frac{1}{4\pi} \sum_{i,j} \beta_{xi} (kl)_i + 2(ml)_j D_{xj} \beta_{xj} \rightarrow 0 \]

Sextupoles are nonlinear elements and reduce the dynamic aperture. In order to keep their strengths low they have to be placed at positions with large dispersion (and large decoupling of the beta function).

Chromatic corrections are more difficult in TBA lattices!
COHERENCE

High brilliance (lateral coherence)
Narrow bandwidth (temporal coherence)
  - long undulators
  - waiting for next light source generation
POLARIZED LIGHT is generated by special undulators:

- ELECTROMAGNETIC UE212 (8-800 eV)
- APPLE II TYPE UE56 (90 eV–3 keV)
SHORT PULSES

STORAGE RING BASED LIGHT SOURCES:

ARE GOOD FOR ➔
- diffraction limited light in the VUV range (~ 100 eV)
- high brilliance in the soft- and hard X-ray regime and related lateral coherence
- any type of polarized light (generated by special insertion devices)

HAVE MADE ENORMEOUS PROGRESS ➔
- energy, position and intensity stability
- Achievement of higher photon energies (also from medium energy electrons)

DO NOT COVER THE NEEDS FOR ➔
- high temporal coherence
- short pulses
FEMTO – Femtosecond X-ray pulses

ALS/Schoenlein, Zholents, Zolotorev
COMPARISON OF LATTICES FOR LIGHT SOURCES AND HEP COLLIDERS

HEP COLLIDER

LHC

→ large circumferences

HEP colliders are composed by long regular FODO cells in the arcs and a few low beta insertions:

Large circumferences are necessary to reach the highest possible energies

\[
\frac{I}{\rho} = e \frac{B}{p} = B_{\max}
\]

nc: 1.6 T
sc: ~ 9 T
**LIGHT SOURCE**

Light Sources are built up by a large number of identical achromat structures.

Large circumferences are wanted to increase the BRILLIANCE and to provide many straights for IDs!

\[
B = \frac{F}{(4\pi)^2 \kappa \varepsilon_x^2}
\]

\[
\varepsilon_{min} = \frac{C_q \gamma^2}{J_x} K \phi_{BEND}^3
\]
WHAT ELSE IS IMPORTANT FOR A LIGHT SOURCE

- **SUPPRESSION OF ENERGY WIDENING EFFECTS**
  Shift of the radiation harmonics from an undulator → intensity fluctuations, broadening of the lines

- **INTENSITY STABILITY**
  Change in background conditions and thermal load on beamline optics and machine components (→ position stability!)

- **POSITION STABILITY**
  Dilution of the emittance → reduced brilliance, intensity fluctuation

- **ENERGY STABILITY**
  Shift of the radiation harmonics from an undulator → intensity fluctuation

- **TUNABILITY**

- **HIGH PHOTON ENERGIES**
SUPPRESSION OF ENERGY WIDENING EFFECTS

- MULTIBUNCH FEEDBACK SYSTEMS
- PASSIVE SUPERCONDUCTING HIGHER HARMONIC CAVITY

3HC COLLABORATION
CEA (Saclay), CERN, Sincrotrone Trieste, PSI

Phase variation along the bunch train (for a partially filled ring) causes a split in frequency for the individual bunches and therefore a suppression of longitudinal multibunch instabilities
INTENSITY STABILITY

TOP-UP INJECTION

Steady state glow at the SLS

POSITION < 1 μm

BPM DOES NOT MOVE!
INTELLIGENT TOP-UP

After 6 hours operation of filling pattern feedback

Without filling pattern feedback

INTELLIGENT TOP-UP
REQUIRES PROPER INJECTION CHAIN!

SLS-BOOSTER:
- reliable
- low power consumption
- small injected beam size

$\varepsilon = 9 \text{ nm (2.4 GeV)}$
$P_{\text{mag}} = 200 \text{ kW}$
**POSITION STABILITY**
- Foundation, magnet support
- Top-up injection
- Fast BPM system
- Orbit FB system

X-Y SCATTER PLOT / 1 SAMPLE/S

$\sigma = 0.6 \, \mu m$

100 s 30 nm
20 days 0.5 \mu m
1 year 1-2 \mu m
INTENSITY STABILITY IS CRUCIAL FOR A HIGH POSITION STABILITY!

BPM DISPLACEMENT

CURRENT

dump beam

top-up @ 200 mA
decaying beam

no movement!

1.5 h

3.5 µm

5 µm

200 mA

120 mA

0

beam current [mA]
POMSH-02SE reading [µm]

TIME

05/05/2002
06:00:00 09:00:00 12:00:00 15:00:00 18:00:00 21:00:00
MAGNET SUPPORT SYSTEM

GIRDER EQUIPPED WITH:
- GIRDER MOVERS
- HLS-SYSTEM
- H-POS MONITORING
- BPM POS MONITORING
ENERGY STABILITY

→ Tuning of RF-frequency

CORRECTING THE AVERAGE HORIZONTAL ORBIT BY ADJUSTING THE RF FREQUENCY AND THUS ADJUSTING THE ELECTRON ENERGY

HIGH INTENSITY STABILITY OF MONOCHROMATOR OUTPUT

\[ \lambda = \frac{\lambda_o}{2\gamma^2} \left( 1 + \frac{K^2}{2} \right) \]
DAY / NIGHT TEMPERATURE VARIATIONS

**CIRCUMFERENCE** of the SLS ring changes with outside temperature.

**RF FREQUENCY** is adjusted to compensate for these changes.
**TUNABILITY**

→ To adjust the photon energy to the needs of the experiment!

**EXAMPLES:**

**ABSORPTION TOMOGRAPHY**

SLS-MATERIAL SCIENCE BEAMLINE

Bone sample damage

**PHASE CONTRAST TOMOGRAPHY**

SLS-MATERIAL SCIENCE BEAMLINE

3-dimensional reconstruction of the vesicular distribution in mouse brains

1 mm³

Resolution

~ 1 μm

Philipp Thurner, EMPA and IBT, Marco Stampanoni, SLS
HIGH PHOTON ENERGIES

IMPORTANT!

TO REACH HIGH PHOTON ENERGIES WITH A MEDIUM ENERGY MACHINE

...... can only get there by:

- Small period undulators (in-vaccum !)
- The use of higher harmonics

Low gap/small period undulators lead to →
  - low beam-gas lifetime
  - low Touschek lifetime
IN VACUUM UNDULATOR U-24 (Spring-8 / SLS)

G. Ingold
T. Schmidt
…… this operation mode creates a series of adverse effects that must be cured:

- SMALL GAPS
  - enhanced beam gas scattering
  (and also Touschek scattering!)
  [sophisticated vacuum system, higher harmonic cavity]

- HIGHER HARMONICS
  - Are destroyed if the energy spread is blown up
  needs therefore perfect cure of multi-bunch instabilities
  [mode shifting, temperature tuning, feedback systems, higher harmonic cavity]
CONCLUSIONS

- Storage ring based Light Sources need a highly optimized lattice to reach the maximum brilliance (coherence).
- Nonlinear compensation must already be optimized with the linear lattice design.
- Large circumferences are wanted to reduce the emittance, i.e. to increase the brilliance and to provide space for many insertion devices.
- Not all user requirements can be met with storage ring based light sources (longitudinal coherence, short pulses).
- A new generation of Light sources (Free Electron Laser) is needed to meet these requirements.
- Stability of intensity, energy and position are crucial issues.
SYNCHROTRON RADIATION CENTRES AROUND THE WORLD
EXTRAPOLATION TO THE YEAR 2100 ...