Construction of the BEAST II Undulator

FEL - Seminar

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BEAST II TEAM

LUX Magnet design
- Geometry and fields of magnets and poles
- Order magnets

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LUX undulator construction
- Order poles
- Design and build support structure
- Measure field

With great support from J. Bahrdt (HZB)
Outline

> LUX Overview

> Undulator Field and Trajectories

> Design parameters & error estimation

> Undulator Design & Construction

> Field Quality Measurement

> Conclusion & Outlook
Laser plasma driven undulator light source - LUX

- High power laser (200 TW) focused into gas target

- Creates plasma channel in which electron bunches are created & accelerated towards highly relativistic energies

- Electrons captured with quadrupole magnets
  Laser outcoupled to diagnostics
- Electrons focused into alternating dipole structure called undulator
  Electrons wiggle around orbit and start to radiate

- Undulators produce tunable light pulses with high intensity in a narrow bandwidth
Hybrid Undulator Field

Field on axis

\[ B_y = -B_0 \sin \left( \frac{2\pi}{\lambda u} z \right) \]

One period = \( \lambda u \) = two dipole fields
Undulator Trajectory - Physics

Field on axis
\[ B_y = -B_0 \sin(k_u z) \]
\[ k_u = \frac{2\pi}{\lambda_u} \]
Lorentz force:
\[ F = q(\vec{v} \times \vec{B}) \]

Transverse velocity:
\[ \beta_x(z) = \frac{k}{y} \cos(k_u z) \]

Amplitude of deflection
\[ K = \frac{\lambda_u e B_0}{2\pi m c} = 0.934 B_0 [T] \lambda_u [cm] \]
Pure machine parameter!

Electrons oscillate, start to emit radiation

Lorentz contraction and Doppler effect:
Central wavelength of radiation cone
\[ \lambda_{obs} = \frac{\lambda_u}{2y^2} \left( 1 + \frac{k^2}{2} \right) \]

Interference effect:
Observed bandwidth shrinks with number of periods \( N \):
\[ \frac{\Delta \lambda}{\lambda} = \frac{1}{N} \]
Undulator Trajectory - Engineering

**Relevant for construction**

Keep fabricational errors as small as possible!

make magnetic field transparent over whole device

Field on axis: \( B_y = B_0 \sin \left( \frac{2\pi z}{\lambda_u} \right) \)

Deflection: \( \beta_x(z) \sim \int B_y \, dz := J_1 = 0 \)

Offset: \( x(z) \sim \int \int B_y \, dz \, dz' := J_2 = 0 \)

Influence of error sources should be smaller than bandwidth

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CR: Schmüser, Dohlus, Rossbach, Behrens – „Free-electron Laser in the Ultraviolet and X-Ray Regime“
BEAST II Design Parameters and Error Estimation

Design considerations:

In vacuum
Periods: 100
λ_u: 5 mm
Fixed gap: 2 mm
Total length: 0.5 m
B_0 = 0.67 T
K = 0.3
γ = 800

λ = 4.26 nm
E = 291 eV
θ = 128 μrad

Δλ
λ = 1%

All other error sources should be in the range of 1%

Difference between global error and local errors

Local errors:
- errors in individual periods
- worsen performance

Global errors:
- Constant error in each period
- lead to different operation range of the whole machine
Pulsed Wire Measurement

Used to measure longitudinally resolved field integrals

Field integrals represent transverse velocity/position change due to a force

Deflection: \( v_x = \int \frac{F_{Lo}}{m} \, dt \sim \int B_y \, dz := J_1 \)

Field integral

\[ J_1(z) = \int_0^{v_z \cdot t} B_y(z) \, dz = B_y \cdot z \]

Release wire:
Short force effect \( \delta t \)

\[ \frac{dx}{dt} = \frac{F \delta t}{m} \quad \Rightarrow \quad dx = \frac{F \delta t}{m} \, dt \]

=> Kick travels along the wire and generates wavefront

\[ dx = -\frac{F \delta t}{2 v_w \cdot m} \, dz \]

At the detector:
Wavefronts sum up as a step function

\[ x(t) = -\frac{\delta t}{2 v_w \cdot m} \int F \, dz \]
Pulsed Wire Measurement

Wire: current circuit!

\[ F_{\text{Lo}} = I \cdot l \cdot B \]

- Current pulse \( I \) flows simultaneously
- Magnetic fields act simultaneously
- Wire gets deflected => acoustic waves!

\[ F_{\text{Lo}} = q \cdot v \cdot B \]

Electron position depends on time

Magnetic fields act in a time-dependent order

Electron gets deflected

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Integrated field

\[ J_1(z) = B_y \cdot z \]

Deflection according to

\[ v_x \]

\[ v_z \]
Pulsed Wire Measurement – Setup

Calibration $c_{cal} = -2707 \, \frac{V}{m}$
Linear regime: $\delta U_{cal} = \pm 26 \, mV$
Conclusion - Manufacturing

Challenge:
Mass production of high precision elements!

Project was rejected by over 30 companies

Solution:
University Workshop!

Stephan Fleig (Master chief)
Christian Reimer (Wire erosion)
Jonas Hoelzer (CNC Milling)
Konstantin Herbst (CNC Milling)
Thank you for your attention!

Acknowledgement

Thank you for your attention!