Investigation of the vibrational stability of synchrotron X-Ray optics using a differential interferometer

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Outlook

- PETRA III Cryo – cooled double crystal monochromators (DCM)
- What kind of vibrations do we have and why are they bad?
- How to measure and assess the vibrations
- Systematic investigations at the DCMs
- Results and design improvements
PETRA III cryo-cooled Double Crystal Monochromator (DCM)

- Crystals
- DCM back plane
- Bragg axis motor
- LN$_2$ transfer tubes
- Cryo-pump
- DCM vacuum chamber

11 different systems according to the same design principle
Initial state of the DCM

- Common Back plane
- Centre of Bragg rotation
- 2nd crystal positioning stages
- Corrugated tubes LN₂ – supply 2nd crystal

- SR-Beam
- Fixed exit

- 1st crystal cage
- 2nd crystal cage

- Corrugated tubes LN₂ – supply 1st crystal
Vibrations and the effect on the beam quality

**Effect of crystal vibrations**

- Real source
- Virtual source
- Virtual source'
- Crystal
- Focusing device
- Focus
- Focus'
- $\Delta s$
- $\Delta \phi$
- $L_c$
- $L_s$
- $L_f$

**Effect of relative movements of beamline optics**

- Source
- $\phi_1(t)$
- DCM vibrations
- $\phi_2(t)$
- Focusing device
- Focus
- $\sigma_s$
- $\sigma_f$
- $L_c$
- $L_s$
- $L_f$

Leads to broadening due to the movement of the virtual source ($\Delta s$)

Leads to broadening due to movement of beam and focus position ($\sigma_f$)
Vibrations measurements using the x-ray beam

- How can we measure and analyze the beam vibrations
- Reproducible methods are required

Focused beam at knife edge

Full beam at slope of rocking curve

Amplifier → Oscilloscope

Pitch scan 2nd crystal

Beam size ~95 μm

Amplifier → Oscilloscope

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Vibrations measurements using the x-ray beam

> Fourier transformation to separate the vibration contributions

\[ \sigma^2 = \sum_{i=1}^{N} c_i^2 \]

> Both methods produced comparable results.
Vibrations measurements using the x-ray beam

Methods working well to define vibration behavior of the beam

Only limited access to the installed DCM during the measurement periods.

Perform vibration measurements, without synchrotron beam

Requires new methods to measure the DCM vibrations

Perform test-experiments under operating conditions

Comparability of DCM vibration and beam vibration is necessary.
Vibrations measurements using a differential interferometer

Reflecting target

Laser interferometer

Sensor heads

Working distance 0-400 mm
Sensitivity 25 pm
Repeatability 2 nm
Bandwidth 10 MHz

Beam vibrations
\( \sigma = 0.30 \) urad

Interferometer: differential signal
\( \sigma = 16 \text{ nm} \rightarrow 0.27 \text{ urad} \)

Interferometer: absolute signal
Mainly from linear part of the vibration
Performed modifications in the DCM

Possible vibration sources in the Cryo-system
Possible reasons for relative movements of the crystals
Other sources of vibration

- Servo-controlled DCM compared to DCM with applied brake
- Low stiffness
- Replaced by rigid aluminum blocks (only for tests)
- Connection in critical direction
- Servo motor for Bragg-Rotation ???
- Corrugated tubes (generate turbulent flow)
- Fixed Exit
- Low stiffness
- Connection in critical direction
- Replaced by rigid aluminum blocks (only for tests)
- Corrugated tubes (generate turbulent flow)
What we learned from these investigations

> Many small improvements but no real breakthrough.

> One source of vibration could be identified

Mainly due to LN2 system

Mainly due to the Bragg axis control

> The actual cause of the vibrations due to LN₂ system was still unclear.

→ So we had to find further investigation methods
Further investigations at the DCMs with a micro-resonator

- Analysis of individual components through specific excitation of the natural frequencies due to micro-resonator.

**Advantages:**
- Selective stimulation of components
- Uniform excitation
- Adjustable frequency
- Minor sensitivity to disruptions
- All natural frequencies visible

Recorded with the DI

Piezo kicker
Pulse generator
Piezo controller
Further Investigations at the DCM

- Analysis of individual components through specific excitation of the natural frequencies
- Integration of a micro resonator in combination with the DI
- Advantages:
  - Selective stimulation of components
  - Uniform excitation
  - Adjustable frequency
  - Minor sensitivity to disruptions
  - All natural frequencies visible

Micro resonator
Further Investigations at the DCMs

- Combined with the DI it is possible to assign specific frequencies to specific components.

![Graph showing Cryfreq = 22 Hz with control and brake data with standard deviations.]

- Problematic frequency range.

- Crystal cage of the 2\textsuperscript{nd} crystal.

- LN\textsubscript{2} Pipe of cryo-feedthrough.
Stability considerations at the installed feedthroughs

- Principle of the original feedthrough with LN$_2$ transfer system to the crystals (FMB-Oxford)

- Corrugated tubes induces strong vibrations

- Isolated vacuum-feedthrough

- Free swinging pipes as a thermal insulator

- Fixation for the pipes

- LN$_2$ Supply 1$^{st}$ crystal

- LN$_2$ Supply 2$^{nd}$ crystal

- Free swinging pipes
LN2-Feedthrough (Prototype 2)

- Optimized
  - for stiffness (stability)
  - thermal insulation
  - LN$_2$ flow behavior
  - manufacturing engineering

- Produced by Selective Laser Melting (SLM)

- corrugated tubes with smoothed inlays
- fixations of the corrugated tubes
- additional fixation of the inlet pipes
- LN$_2$ connection chamber
- smoothed feeding of the LN$_2$ pipes
Present state of the DCM after Upgrade

Before upgrade in control mode
\( \sigma = 0.23 \mu \text{rad} \)

After upgrade control mode
\( \sigma = 0.12 \mu \text{rad} \)

After upgrade brake mode
\( \sigma = 0.05 \mu \text{rad} \)

- Improved LN\textsubscript{2} Feedthrough
- Avoidance of long free-swinging components
- All corrugated tubes with inlays
- New routing of the tubes with additional fixation
Conclusions

> A “Differential Interferometer” for vibration measurements directly at the DCM-crystals.

> It was shown that the measurements of the DI correspond to those of the measured vibration of the SR-beam

> Two sources of vibrations have been identified:
  - Vibrations due to the LN$_2$ system
  - Vibrations due to the Bragg axis servo-motor

> Weak points in the mechanical design of the DCM have been identified

> Constructive improvements in DCMs were installed.

> In the best case ~50nrad stability (RMS) has been achieved with the upgraded DCM.
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Thank you for your attention