Double Crystal Monochromator Control System for the Energy Materials In-Situ Laboratory Berlin

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Challenges

- Complex beamline
- Experimental constructions
- >15 EPICS IOCs
- New motion control hardware
- Follow devices on-the-fly or predefined path
- Fast and precise positioning
- Low-level programming on motion controller
- Support of low-level features in higher level software
- Diagnostic tools needed by scientist and software engineers
- Device based framework and adaption to old monochromator control software
Motion Control Hardware
Software Stack

- EPICS IOC
  - Database
  - C++ Model
  - Specific features can be added
- Clients: EMP2, SPEC, LISE, ...
  - Evaluating: Bluesky, Phoebus
  - Display Manager
  - Collaborate, Share Code
  - Python/Jython
  - Reduce overall number of programming languages, tools.

PLC Program

```
... if collision stop motors endif ...
```

Motion Program

```
SPLINE
X Y Z
X Y Z
X Y Z
M33 == 1
X Y Z
...
```
EPICS Support

EPICS CA or DB Access

Device based C++ Design Pattern

Mono Geobrick Controller

PGM / DCM/ Hexapod ...

multiAxis

singleAxis

pmacAxis

PMAC Controller

Motor Record

Mono GUI Tools User

Derived

Used

Mono

GUI

Tools

User
Filters for encoder positions

Types of filters implemented include:

- Exponential filter
- Moving average filter
- Spike detection

Figure: Exponential filter implementation for encoder readouts.
Algorithm for smooth on-fly velocity profile generation

- Trapezoidal shaped motion not sufficient
- High precision point-to-point moves
- Closed-loop moves
- Multidimensional path
- Jerk limited profile
- Motion profiles continuous in 2nd derivative (acceleration)
- On-the-fly generated path predictable at any point of the trajectory
- Possible triggers in sync with movements

Figure: Spline move building blocks
Motion States

Constant Velocity
- Calculate/Receive New Velocity
- Single Spline Segments

Big velocity change > 4*\alpha

Acc-Scurve-Start-Jerk
- Const Acc
  - Single Spline Segments
  - Max velocity of Const Acc

Small velocity change < 4*\alpha

Full Sigmoid Profile

Acc-Scurve-End-Jerk
CR1/CR2 Controller

Target Position
Maximum: Velocity, Jerk, Acceleration

Controller

Motion State Machine

Smooth Motion Profile

Encoder / Filter

Mechanics

Drives

1) Worm Gear
   Gear Box
   Timing Belt
2) Sine Drive

Figure: Motion state machine output.
Long Range Spline Moves

DCM
1 Axis closed-loop
PID Vff
+ Programmed velocity profile

PGM
Continuous mode

Figure: Crystal rotation velocity and cryo axis velocity
Closed Loop End Positioning

- Generate Spline
- Changing gain close to target
- Smooth approach
- In-position band
- No direction inversion
- No vibrations
- Predictable path
- Good results for full stop directly to end-position
- Mechanical errors and non-linearities
- Extend algorithm for fast closed-loop deceleration phase

Figure: Deceleration phase
Motion Program Logic (DCM)

- **Start**
  - Distance to target and FE small, short range
  - Backlash Logic
  - Distance to Target or FE big
  - Linear Motion
  - Distance to target and FE small, short range
  - Mid range \( t/2 \)
  - Short range
  - Onfly algorithm
  - Linear Motion
  - End Positioning
  - Piezo Positioning
Piezo motors for crystal parallelism

Table: Motors and their ranges

<table>
<thead>
<tr>
<th>Axis</th>
<th>Motor</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal translation</td>
<td>Stepper motor</td>
<td>70mm</td>
</tr>
<tr>
<td></td>
<td>Piezo motor</td>
<td>90 μm</td>
</tr>
<tr>
<td>Crystal Pitch</td>
<td>Piezo motor</td>
<td>90 μm</td>
</tr>
<tr>
<td>Crystal roll</td>
<td>Piezo motor</td>
<td>90 μm</td>
</tr>
</tbody>
</table>

Figure: Ray diagram and degrees of freedom of piezo motor system

Figure: Open-loop system
Closed loop system

Requirements
1. Setpoints in micro radians
2. Pitch and roll positioning in closed loop
3. Stable and fast closed-loop control

$X_1 =$ distance between pitch and height encoders.
$X_2 =$ distance between roll and height encoders.

Procedure
- Open loop system identification
- Estimation of MIMO system-state space model
- Stability analysis
- Pole Zero placement design
- Closed loop tuning of the interconnected system
- Implementation and testing
Results

Figure (a)
A pi signal response of the measured system and estimated system

Figure (b)
The closed-loop performance of the roll piezo motor
Diagnostic: Continuous Feedback

EPICS wf-records monitored by client software

Feedback module processes data

Poll task checks/reads data package

PLC code calculates and fills data package in user buffer
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# References