Automated Operation of the Metrology Light Source Electron Storage Ring

Thomas Birke

based on work of T. Birke, M. Abo-Bakr, J. Feikes, B. Franksen, M. v. Hartrott, G. Wüstefeld

May 2009 – Particle Accelerator Conference ‘09 – Vancouver, BC, Canada
What is the Metrology Light Source (MLS)?

- Low energy $e^-$ storage ring
- Metrology and technological developments in UV/XUV as well as IR and THz
- Optimized for generation of coherent SR in FIR/THz
- Owner: Physikalisch-Technische Bundesanstalt (PTB) - German national metrology institute
- Built according to PTB specifications and operated by BESSY which is now part of the new Helmholtz Zentrum Berlin für Materialien und Energie
- In regular user operation since April 2008
What is the Metrology Light Source (MLS)?

- Low energy $e^-$ storage ring
- Metrology and technological developments in UV/XUV as well as IR and THz
- Optimized for generation of coherent SR in FIR/THz
- **Owner:** Physikalisch-Technische Bundesanstalt (PTB) - German national metrology institute
- Built according to PTB specifications and operated by BESSY which is now part of the new Helmholtz Zentrum Berlin für Materialien und Energie
- In regular user operation since April 2008
Operating the Metrology Light Source

- Wide range of operating modes and parameter settings
  - Current: 1 pA (a single electron) up to 200 mA
  - Energy: 105 MeV – 630 MeV
  - Momentum compaction factor $\alpha$: varies by factor of $\sim 1000$

- Electromagnetic Undulator
  - strong non-linear fields enforce compensation with correction coils using feed-forward system
    – otherwise impossible to accumulate and store beam

- Injection setup differs from operation setup
  - Orbit bump
  - Asymmetric sextupole settings
  - RF frequency modified
Automated Operation of the Metrology Light Source Electron Storage Ring

Operating the Metrology Light Source

- Specialties require complex procedures
- Setup changes often according to user demands
  - Even **on short notice**
- Energy ramped before and after injection with minimum loss of beam
  - Special procedure
- Energy Ramp used as degaussing cycle
  - **But: Magnets not driven into full saturation**
    → Machine performance is very sensitive to magnet-setting-errors
- Optics change program to change momentum compaction factor
  - Currently done manually – program is in development
Operating the Metrology Light Source

• Several tasks to be performed by operation personnel
  • Inject up to desired current
  • Ramp energy – before and after injection as well as on user-demand
  • Change momentum compaction factor
  • All tasks require several actions and may require sub-tasks
  • Any error (esp. in magnet settings) may strongly deteriorate machine performance

• Operated by BESSY/HZB staff for PTB
  • Paid customer service
  • Deliver high operational reliability with minimum personnel effort

• High degree of automation required!
Operating the Metrology Light Source

• Several tasks to be performed by operation personnel
  • Inject up to desired current
  • Ramp energy – before and after injection
  • Change momentum compaction factor
• All tasks require several actions and may require sub-tasks
• Any error (esp. in magnet settings) may strongly deteriorate machine performance

• Operated by BESSY/HZB staff for PTB
  • Paid customer service
  • Deliver high operational reliability with minimum personnel effort

• High degree of automation required!
Operating the Metrology Light Source

• Several tasks to be performed by **operation personnel**
  • Inject up to desired current
  • Ramp energy – before and after injection as well as on user demand
  • Change momentum compaction factor
  • All tasks require **several actions** and may require **sub-tasks**
  • Any error (esp. in magnet settings) may **strongly deteriorate** machine performance

• Operated by **BESSY/HZB** staff for **PTB**
  • Paid customer service
  • Deliver **high operational reliability** with minimum personnel effort

• **High degree of automation required!**
Operating the Metrology Light Source

• Several tasks to be performed by operation personnel
  • Inject up to desired current
  • Ramp energy – before and after injection as well as on user-demand
  • Change momentum compaction factor
  • All tasks require several actions and may require sub-tasks
  • Any error (esp. in magnet settings) may strongly deteriorate machine performance

• Operated by BESSY/HZB staff for PTB
  • Paid customer service
  • Deliver high operational reliability with minimum personnel effort

• High degree of automation required!
Operating the Metrology Light Source

- Several tasks to be performed by operation personnel
  - Inject up to desired current
  - Ramp energy – before and after injection as well as on user-demand
  - Change momentum compaction factor
  - All tasks require several actions and may have sub-tasks
  - Any error (esp. in magnet settings) may strongly deteriorate machine performance
- Operated by BESSY/HZB staff for PTB
  - Paid customer service
  - Deliver high operational reliability with minimum personnel effort
- High degree of automation required!
Software System

• Several localized sub-tasks already realized in separate applications
  • Energy Ramp
  • Optimizing microtron output
  • Momentum compaction factor – semi-automatic by restoring snapshots of magnet-settings and manually adjust the RF-Frequency

• What action to perform how and when? – Organized by operator
  • Expertise is in the heads – sometimes even documented
  • All signals needed for deciding what to do are available in control system (EPICS – Experimental Physics and Industrial Control System)

• Decided to develop one central application to coordinate necessary tasks
  • Operation Master
  • Software model: State Machine
Software System – Finite State Machine (FSM)

• Set of States of a described system
  • States describe all possible states of the machine
  • Active state resembles current machine-state
  • Software and machine are to be kept in sync
• Transitions between these states
  • Well defined conditions force transitions into other states
  • All transitions/conditions of active state checked on every incoming event
• Change of a control system process variable
• Timeout
• User interaction through graphical user interface
  • Actions may be performed when entering a state and/or on transition
Software System – Finite State Machine
Simple Beam-Scrubbing Engine

when current < minLimit
do switchInjection(ON)

waiting @630 MeV

ramp energy down
cycle magnets
turn on injection
injecting @105 MeV
turn off injection
ramp energy up

when current > maxLimit
do switchInjection(OFF)

when modulator fails

recover modulator

when timeout

Thomas Birke – May 2009 – PAC’09 – Vancouver, BC, Canada
**Software System – Finite State Machine**

**Simple Operation Engine**

1. **Waiting @xyz MeV**
   - **When** current < minLimit
   - **Do** switchInjection(ON)
   - **When** operator forces energy ramp

2. **Injecting @105 MeV**
   - **When** current > maxLimit
   - **Do** switchInjection(OFF)
   - **When** timeout
   - **Do** switchInjection(OFF)
   - **Turn off injection**
   - **Ramp energy down**
   - **Turn on injection**
   - **Cycle magnets**

3. **Recover modulator**
   - **When** modulator fails

4. **Force energy ramp**
   - **Waiting @xyz MeV**
   - **Ramp energy up**

Thomas Birke – May 2009 – PAC’09 – Vancouver, BC, Canada
State Machine – Current Version

- **Blue**
  - in sequence states/transitions “expected”

- **Orange**
  - out of sequence states/transitions “unexpected”

- Image created by *GraphViz*

- Input to *GraphViz* created by *Operation Master*
**Operation Master – Successful Run**

- Performed well for two unmanned weeks during holiday break 2008/2009
  - Just one unidentified problem with microtron modulator PLC
  - Manual intervention necessary
  - Action is now part of command sequence to recover from microtron errors

![Graph showing beamcurrent over two weeks](image)

One injection cycle

Energy

Current

beamcurrent over two weeks
**Operation Master – Development**

- Whole system *not* developed by design according to full specification
  - **State Engine** – as generic as possible
  - **State Machine** – unspecified, very simple first version

- **Evolutionary** development process
  - **Experiences** of commissioning and daily use of application itself
  - Yet unhandled states only identified when using the application
  - Solutions to problems often roughly sketched → refinement phase
  - Clear view of solution often arises during discussions between developer and users/scientists → close cooperation drives development
  - Numerous small development steps
  - Some removed in favor of other solution or have proven obsolete during further commissioning
**Operation Master – Implementation**

- Current version written in **Tcl/Tk**
- Proper choice for **rapid prototyping**
- **Monolithic** application
- State machine, state engine, graphical user interface (GUI)

- Only one instance can be running at a time
- Application only visible on a single screen
Operation Master – Future

- *Operation Master* redesigned and **new implementation** in progress
- **Headless server** process
- State machine and state engine only
- Written in **Python** programming language
- All interaction using **control system process variables**
- **Remote-control** from other application

- Use of **standard control system tools** (EPICS-Toolkit) for
  - **Display** – graphical display manager can be run on **any screen**
  - EPICS Channel Access Security used to control permissions
  - **Alarm monitoring** and **logging** – operator notification and analysis
  - **Archiving** – for later analysis and debugging
Conclusion

• Operation Master: **indispensable operator instrument** since day one

• **Minimizes errors** by performing complex command sequences

• Implements **standard mechanisms** to set up certain states as well as to recover from failure situations

• Will be **extended** to cover all **future tasks** at MLS as well

*Experiences and success encourage using the same system for existing as well as future projects at BESSY/HZB*