



**HELMHOLTZ
ZENTRUM BERLIN**
für Materialien und Energie

Automated Operation of the Metrology Light Source Storage Ring

Thomas Birke

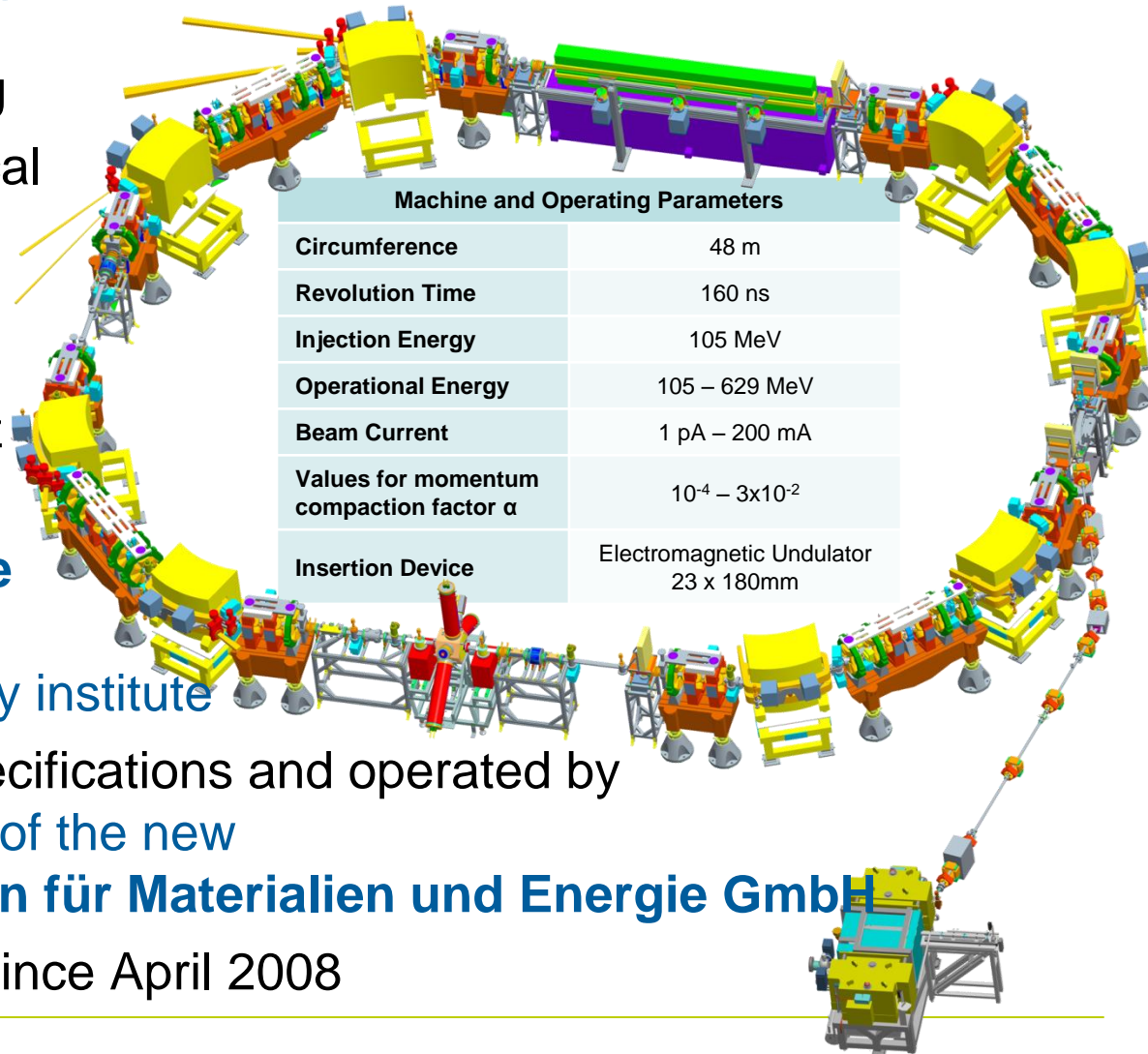
based on work of

T. Birke, M. Abo-Bakr, D. Engel, J. Feikes, B. Frankesen, M. v. Hartrott, G. Wüstefeld, ...

October 2009 – ICALEPCS'09 – Kobe, Japan

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 GmbH**
- In regular user operation since April 2008



Machine and Operating Parameters

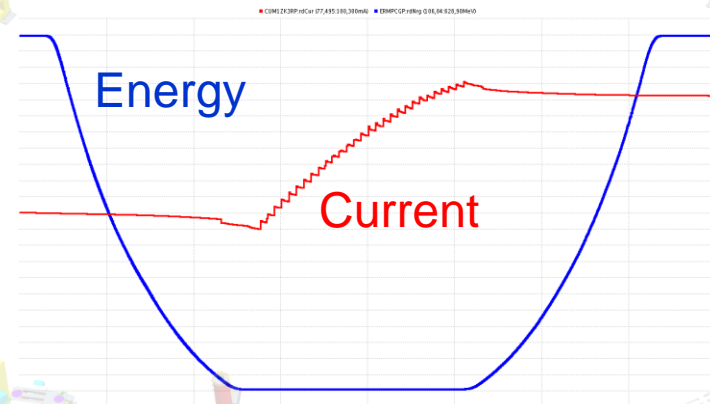
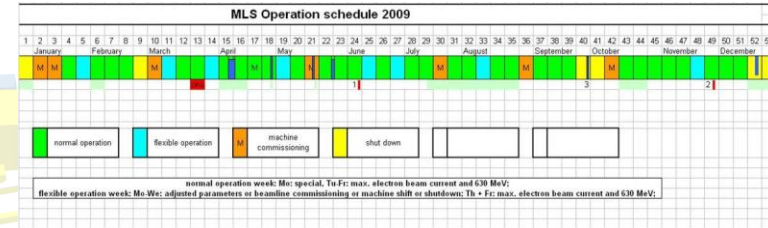
Circumference	48 m
Revolution Time	160 ns
Injection Energy	105 MeV
Operational Energy	105 – 629 MeV
Beam Current	1 pA – 200 mA
Values for momentum compaction factor α	$10^{-4} - 3 \times 10^{-2}$
Insertion Device	Electromagnetic Undulator 23 x 180mm

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 – 629 MeV**
 - Momentum compaction factor α : varies by factor of **~1000**
- Electromagnetic Undulator
 - strong **non-linear fields enforce compensation** with correction coils using fully automatic **feed-forward system** – otherwise impossible to accumulate and store beam
- Injection setup differs from operation setup
 - Orbit bump
 - Asymmetric sextupole settings
 - RF frequency modified

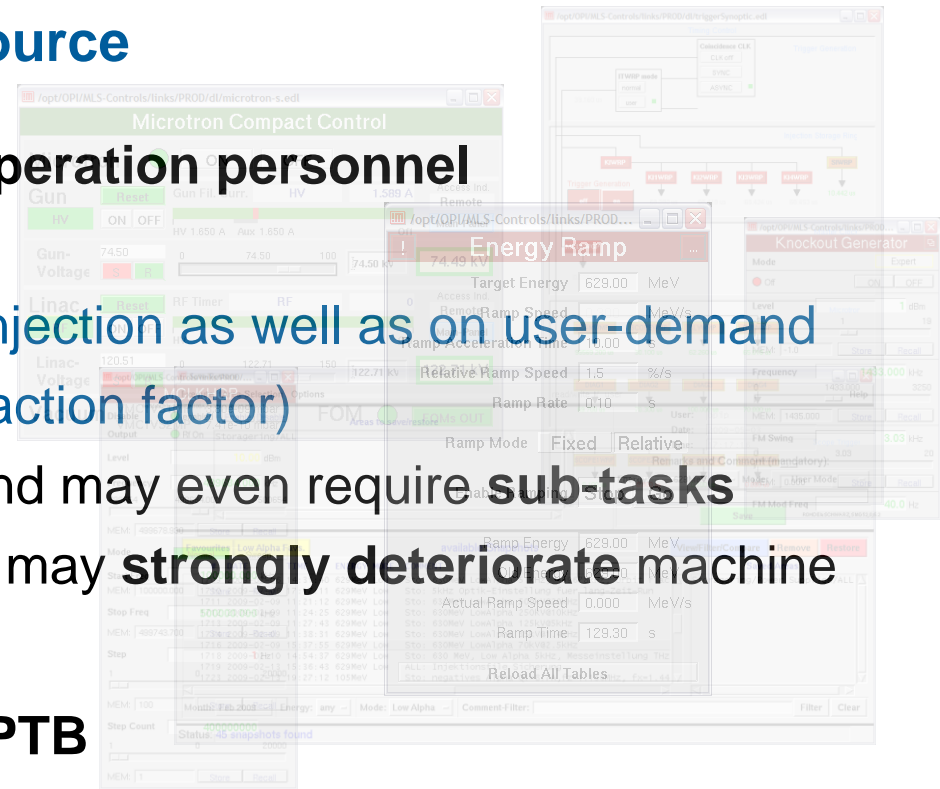
Operating the Metrology Light Source

- Specialties require complex procedures
- Setup changes often according to user demands
 - **Even on short notice**
- **Energy Ramp** before and after injection with minimum loss of beam
 - **Special procedure**
 - **also 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
 - **Another special procedure** (similar to Energy Ramp)



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 optics (momentum compaction factor)
- All tasks require **several actions** and may even 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 maximum transparency and minimum personnel effort
- **High degree of automation required!**



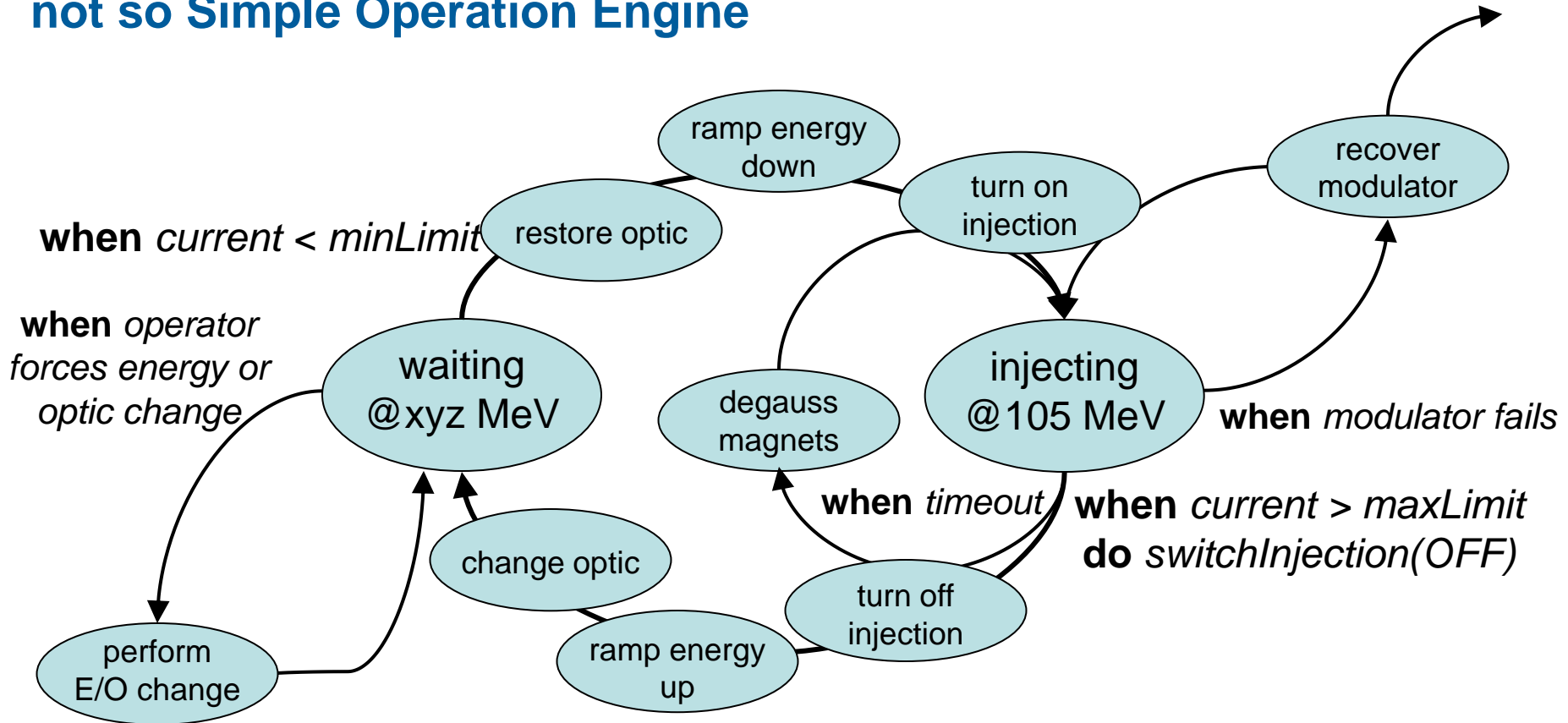
Software System – Status at the Beginning

- Several localized sub-tasks already realized in separate applications
 - Energy Ramp, Optics Change (Momentum Compaction Factor)
 - Optimizing microtron output
 - Orbit Correction, RF Master Clock Controller, ID-controls...
- **What** action to perform **how** and **when**? – Organized by operator
 - Expertise is in the heads – sometimes even documented
 - All signals needed to decide what to do and when 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: **Finite State Machine**

Software System – Finite State Machine (FSM)

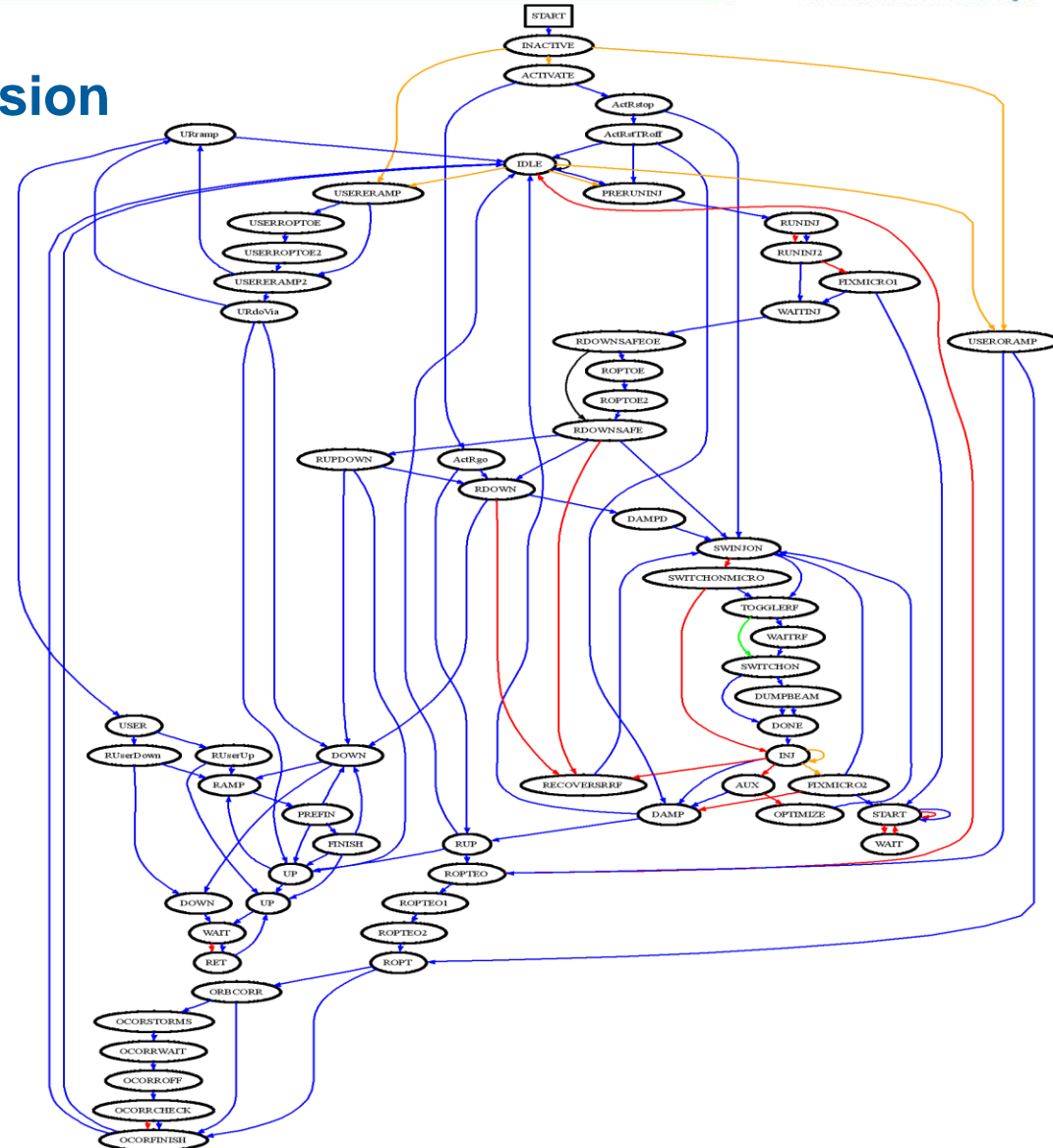
- Set of **States** of a described system
 - *States* represent all possible (known) states of the machine
 - *Active state* resembles current machine-state
 - Software and machine are to be kept in sync
- **Transitions** between these states
 - Well defined conditions unambiguously force *transitions* into other states
 - All *transitions*/conditions of active state checked on every incoming event
 - Change of a control system process variable
 - Timeout
- **Actions** may be performed on transition and/or when entering a state

Software System – Finite State Machine not so Simple Operation Engine



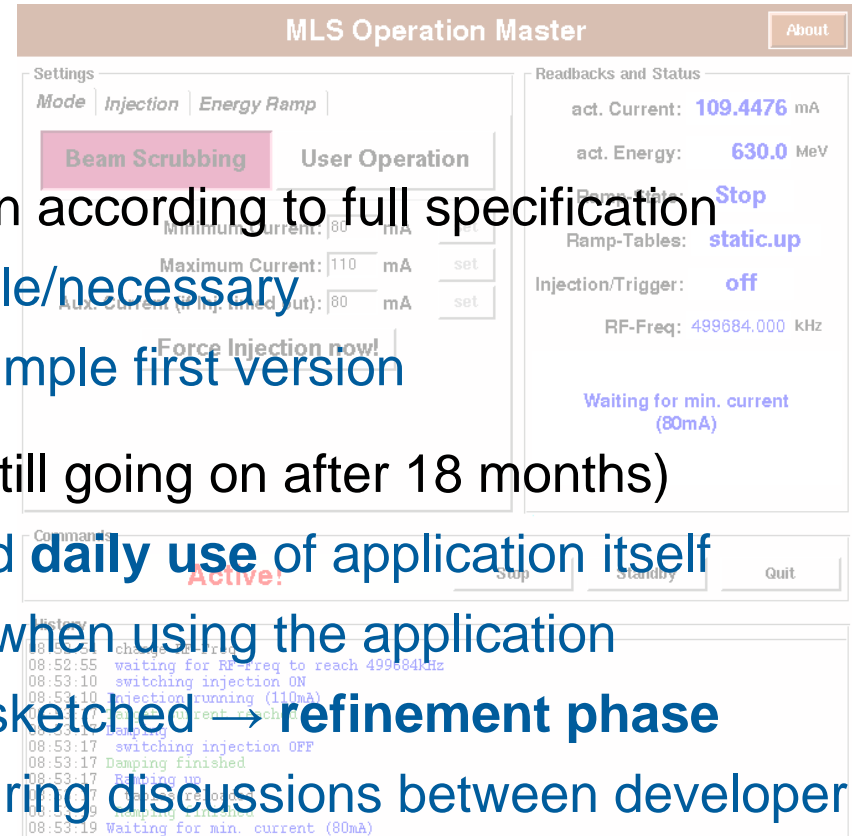
State Machine – Current Version

- **Blue**
 - In-Sequence transitions “expected”
- **Orange**
 - Out-of-Sequence transitions “unexpected” or Operator interaction
- **Red**
 - Error transitions
- Image created by *GraphViz* (www.graphviz.org)
- Input to *GraphViz* created by *Operation Master*



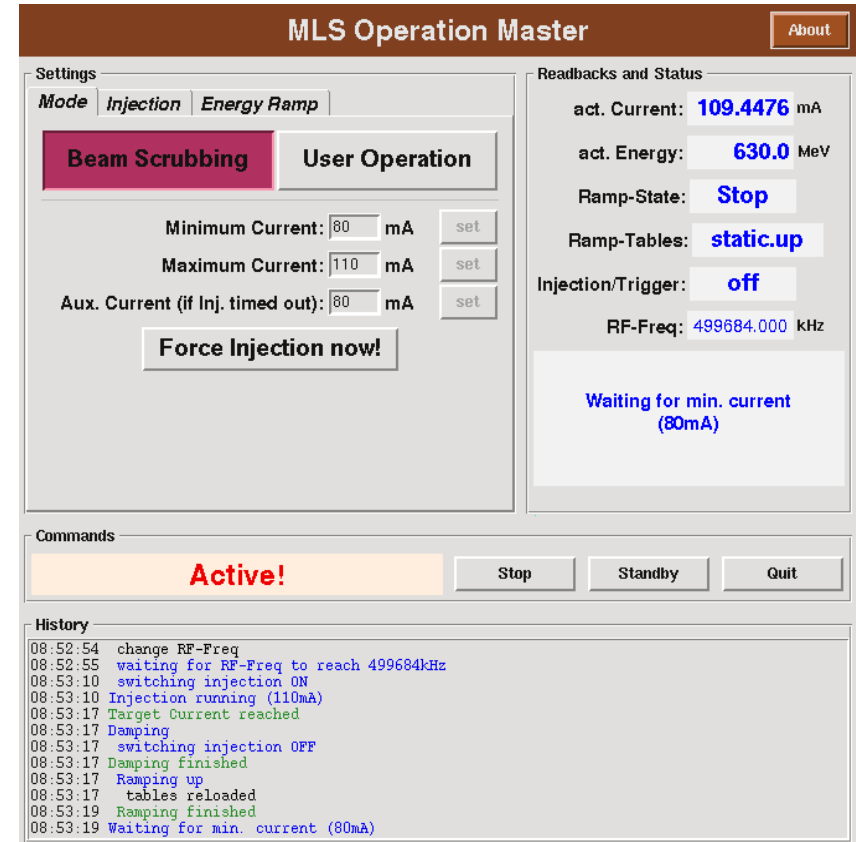
Operation Master – Development

- Whole system *not* developed by design according to full specification
- **State Engine** – as generic as possible/necessary
- **State Machine** – unspecified, very simple first version
- **Evolutionary** development process (still going on after 18 months)
 - **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

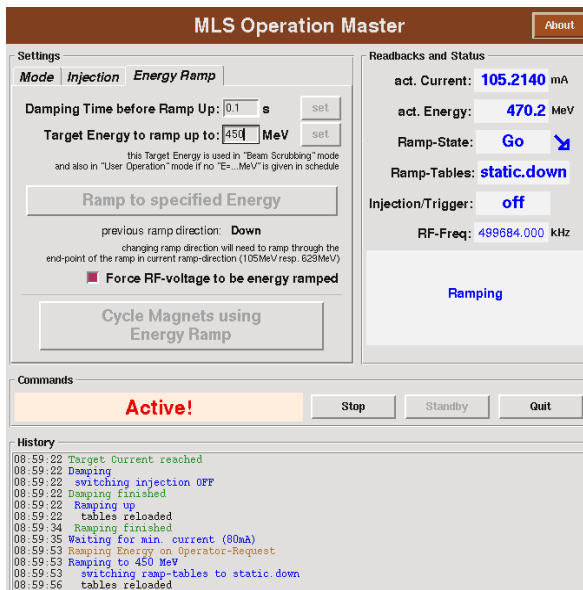


Operation Master – Implementation

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



The screenshot shows the 'MLS Operation Master' interface. It has a top bar with 'About' and a 'Settings' section with 'Mode' set to 'Injection' and 'Energy Ramp'. There are two main tabs: 'Beam Scrubbing' (highlighted in pink) and 'User Operation'. Under 'User Operation', there are input fields for 'Minimum Current' (80 mA), 'Maximum Current' (110 mA), and 'Aux. Current (if Inj. timed out)' (80 mA), each with a 'set' button. A 'Force Injection now!' button is also present. On the right, the 'Readbacks and Status' section shows 'act. Current: 109.4476 mA', 'act. Energy: 630.0 MeV', 'Ramp-State: Stop', 'Ramp-Tables: static.up', 'Injection/Trigger: off', and 'RF-Freq: 499684.000 kHz'. A status message at the bottom right says 'Waiting for min. current (80mA)'. Below the settings is a 'Commands' section with a large 'Active!' indicator and buttons for 'Stop', 'Standby', and 'Quit'. A 'History' section at the bottom shows a log of events.



This screenshot shows the 'MLS Operation Master' interface in a different state. The 'Mode' is still 'Injection' and 'Energy Ramp'. The 'Damping Time before Ramp Up' is set to 0.1 s. The 'Target Energy to ramp up to' is 450 MeV. There are buttons for 'Ramp to specified Energy' and 'Cycle Magnets using Energy Ramp'. The 'Readbacks and Status' section shows 'act. Current: 105.2140 mA', 'act. Energy: 470.2 MeV', 'Ramp-State: Go', 'Ramp-Tables: static.down', 'Injection/Trigger: off', and 'RF-Freq: 499684.000 kHz'. A status message at the bottom says 'Ramping'. The 'Commands' section shows 'Active!' and buttons for 'Stop', 'Standby', and 'Quit'. The 'History' section shows a log of events.

- **But:**
 - Only one instance can be running at a time
 - Application only visible on a single screen
 - **Idea:** split FSM and GUI, simplify interfaces
 - Rewrite in *Python* considered

Operation Master – Future (as planned in spring 2009)

- *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 applications
- 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

Operation Master – current state

- Operation Master redesigned ~~and new implementation in progress~~ *and modified*
 - **Headless server** process
 - State machine and state engine only
 - ~~Written in Python programming language~~ *to keep the well-known, easily maintainable and settled but still evolving State Machine code*
 - All interaction using **control system process variables**
 - **Remote-control** from other applications
- 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

Operation Master – Implementation

- Current version written in **Tcl/Tk**
- **GUI** has been factored out
- All interaction via **EPICS PVs**
- User as well as other software components (IPC)

MLS Operation Master Remote Control Panel Version of MLS Operation Master: V2.11 - (rel. 090929-1349)

Settings

Mode: **Injection** | Energy Ramp | Optic Ramp

Injection Timeout: 15 min
 RF-Freq. for Injection: 499710 kHz
 max. RF-Freq. step-size: 50 kHz

Dump Beam before next Injection
 Set RF-Frequency before Injection
 Toggle V01PMP between Injections
 Switch off Microtron between Inj.
 Set Septum to 0.0 between Injections
 Run MicLinac-optim. during Inj.

Readbacks and Status

act. Current: 119.803 mA
 act. Lifetime: 9.550 h
 act. Energy: 629.0 MeV
 Ramp-State: Stop
 Ramp-Tables: Up
 Synchr.-Freq.: 5 kHz
 Injection/Trigger: off
 RF-Freq (rdbk): 499710.000 kHz

getting rmsH
 OCCORWAIT Timeout: 8 s

Commands

Active! | Deactivate

History

```

09:24:57 switching injection ON
09:24:57 Injection running (120mA)
09:25:52 Target Current reached
09:25:52 Damping
09:25:57 Damping finished
09:25:57 Ramping up
09:25:59 tables reloaded
09:28:14 Ramping finished
09:28:14 checking existence of Optic Ramp tables
09:28:14 switching to LowAlpha tables
09:28:14 preparing to ramp Optic E->O
09:28:15 Ramp Optic E->O
09:28:20 Ramp Optic
09:28:20 getting rmsH
09:28:25 running automatic Orbit Correction for a few seconds
    
```

MLS Operation Master Remote Control Panel Version of MLS Operation Master: V2.11 - (rel. 090929-1349)

Settings

Mode: **Injection** | Energy Ramp | Optic Ramp

Minimum Current: 60 mA
 Maximum Current: 120 mA
 Aux. Current (if Inj. timed out): 90 mA

Force Injection Now!

Readbacks and Status

act. Current: 87.780 mA
 act. Lifetime: 0.088 h
 act. Energy: 105.0 MeV
 Ramp-State: Stop
 Ramp-Tables: Up
 Synchr.-Freq.: nan kHz
 Injection/Trigger: on
 RF-Freq (rdbk): 499710.000 kHz

Injection running (120mA)
 INJ Timeout: 4:01 min

Commands

Active! | Deactivate

History

```

08:57:55 tables reloaded
08:58:06 Ramping finished
08:58:06 tables reloaded
08:58:06 Switching injection ON
08:58:06 Damping
08:58:11 Damping finished
08:58:11 Microtron On?
08:58:11 Microtron is on
08:58:11 change RF-Freq
08:58:11 waiting for RF-Freq to reach 499710kHz
08:58:12 switching injection ON
08:58:12 dumping beam
08:58:21 partial beam-loss (11.8 mA -> 4.1 mA, 65% loss)
08:58:21 beam dumped
08:58:21 Injection running (120mA)
    
```

- **So:**
- *Operation Master* now is a windowless background process (run on a central server)
- Can be monitored/controlled from anywhere
- Simplified interfaces lead to even more stable machine operation

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 standardized tasks** at MLS as well

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