AVAILABILITY ANALYSIS AND TUNING TOOLS AT THE LIGHT SOURCE BESSY II

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ABSTRACT

The 1.7GeV light source BESSY II features about 50 beamlines overbooked by a factor of 2 on the average. Thus availability of high quality synchrotron radiation is a central asset. Users at BESSY II can base their beam time expectations on numbers generated according to the common operation metrics [1]. Major failures of the facility are analyzed according to [1] and displayed in real time, analysis of minor detriments are provided regularly by off line tools. Many operational constituents are required for extraordinary availability figures: meaningful alarming and dissemination of notifications, complete logging of program, device, system and operator activities, post mortem analysis and data mining tools. Preventive and corrective actions are enabled by consequent root cause analysis based on accurate eLog entries, trouble ticketing and consistent failure classifications.

OPERATIONAL MODES

Multibunch hybrid mode

- 298mA total current
- Top-up injections
- 300 bunches 100 buckets gap
- 5 special bunches:

• 4mA purity controlled camshaft bunch in center of gap,

- 3 * 4mA bunches opposite of gap for fs-slicing [2,3],
- 3mA PPRE bunch close to end of gap resonantly horizontally excited for pseudo-single bunch experiments [4].

Single bunch mode

• Single 14mA purity controlled bunch for time resolved experiments (2-3 wk/y)

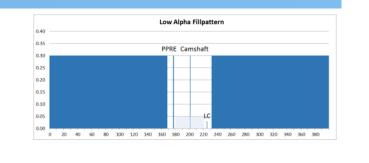


Low Alpha mode [5]

- Even filling of
 - 100mA (short pulse mode) or
 - 15mA (THz mode, non-bursting coherent synchrotron radiation)
- Decaying beam injections every 8h (2-3 wk/y)
- 128ns dark gap
 - Camshaft at center
 - Horizontally excited PPRE bunch close to start of gap
 - <30µA Ultrashort low current bunch close to end of gap

PTB mode

• Conditions according to specific experimental requirements. Availability is 100% as long as facility is functional



• Top-up injections

0.00 0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380

IMPLEMENTATION OF THE METRICS

Metric evaluated in real time since 2016 determining *primary*

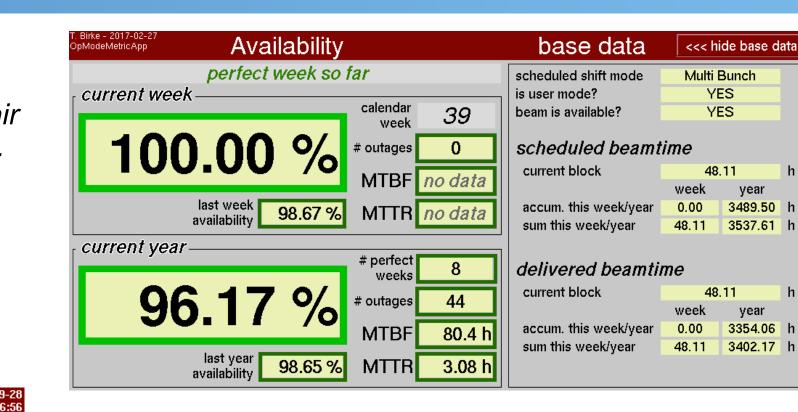
- low beam: $I < I_{tol}$ with $I_{tol} = I_{nom} * 90\% = 223mA$
- no beam: $I < I_{min}$ with $I_{min} = I_{nom} * 66\% = 165mA$

Typically $I_{nom} = 298mA$ and $LT_{min} = 5h$, but currently $I_{nom} = 248mA$ and $LT_{min} = 4.2h$. Temporary removal of third harmonic cavities for repair imposes lifetime and impedance heating constraints.

and secondary failure modes

- **distorted orbit**: BPM RMS deviation > 80µm or no orbit feedback running
- **low lifetime**: beam $LT < LT_{min}$ with LTmin = 4.2h top-up constraint
- **beam blowup**: $\sigma > \sigma_{nom} * 130\%$ horizontally as well as vertically
- distorted fillpattern: $|I_{bunch} I_{bunchNom}| > 10\% * I_{bunchNom}$
- **bad purity**: *pur < 500*
- Limits differ depending on operational/shift mode.
- Shift mode is determined from official beam time schedule and may be overridden.
- Primary failures are "outages" starting at time of event and ending as nominal values are restored and beam is available for the users again.
- Usertime of $T_{user} < 1h$ is not counted as usertime but accounted to the preceding or follow-up outage.

| 8-05-13 - Birke : 0.2.5 | Operation Mode | | | | | switch to Overview Panel | | | |
|---|---|---|-------------------------------|----|---------------|--|-----------------|----------------|--|
| hift: | active mode real resulting operation mode | scheduled mode from Operation Calendar Shift Mode Week Mode | | | if op | erride mode erational mode is anged on the fly | | Bonus Time? | |
| previous: night shift | Multi Bunch | М | ulti Bunch | | - 1 | not set - | | - | |
| current: morning shift | Multi Bunch | М | ulti Bunch | | - 1 | 10t set - | | - | |
| next: late shift | | | Multi Bunch | | - not set - | | | - | |
| after next: night shift | Multi Bunch | Multi Bunch | | | - not set - | | | _ | |
| - primary failure mode | | < | limits & min. til | | es — 90 % | | min time 3 s | time | |
| no beam secondary failure modes — distorted orbit low lifetime beam blowup distorted fillpattern bad purity | | | no beam | 6 | 57 % | | 3 s | | |
| | | < | BPM RMS H/V lifetime (min) | |)8 mm .2 h | 0.08 mm | 60 s 30 s | | |
| | | | beamsize H/V | 10 | 00 µm | 110 µm | 60 s | | |
| | | < | fillpattern | | 10 % | | 60 s | | |
| | | < | purity (min) | 50 | 00 | | 300 s | | |
| 🔵 beam | unrelated usertime | < | | _ | | | 3600 s | | |
| | | | | | | | | | |



formance is visible in unambiguous figures.

2013

96.5 %

42.9 h

1.52 h

105

Availability of synchrotron radiation as percentage of

"promised" scheduled beamtime as well as MTBF and MTTR

are calculated on a per week and per year basis. Overall per-

Same metric has been back-calculated for better comparison.

2015

97.6 %

43.3 h

1.03 h

90

2016

98.7 %

70.4 h

0.91 h

68

2014

92.9 %

39.8 h

2.83 h

136

A week without any outages and 100% availability is tagged "perfect week" internally.

Metric evaluation data and detailed live machine status is available via

web-browser on mobile and desktop [6].

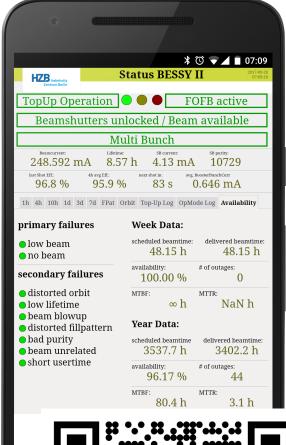
2017 (part)

96.2 %

80.4 h

3.1 h

44



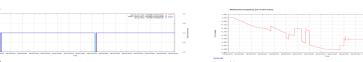


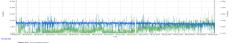
OPERATIONAL TOOLS











- Crucial parameters are permanently checked against properly set boundaries.
- Boundaries are much smaller to alarm operations crew so they can take precautions to prevent any secondary failures.
- A hardware parameter check has been set up to prevent an top-up injection with a too low booster synchrotron current. This prevents top-up interruptions that would enforce closure of beamshutters.

| Low Alpha | 0 | I<1mA and (BS locked or PSI off, | | | reset d | reset disable flags | | |
|-------------------------|--------------|----------------------------------|---------|-----------------|----------------|---------------------|---|--|
| arameter | | Actual Value | disable | LOW | HIGH | Errors | | |
| urrent | | 248.225 mA | | 180.000 mA | 300.000 mA | 0 | R | |
| fetime | | 8.29 h | | 4.40 h | 10.00 h | 0 | R | |
| urity | | 7253 | | 1000 | inf | 0 | R | |
| eedbacks/FeedForwards » | | FDBK/FFWD OK | | - | BK/FFWD warnii | 0 | R | |
| F Systems » | | RF OK | | - | RF warning | 0 | R | |
| /aveform Generators » | | WfGen OK | | - | WfGen warning | 0 | R | |
| ooster | | Normal Operation | | - | Standby Mode | 0 | R | |
| ransfer Line » | | ОК | | - | TLine Warning | 0 | R | |
| jection Status | | Enabled | | OFF | + | 0 | R | |
| une | Horizontal | 1060.2 kHz | | 1055.0 kHz | 1065.0 kHz | 0 | R | |
| | Vertical | 907.5 kHz | | 900.0 kHz | 915.0 kHz | 0 | R | |
| PMZR Average | Horizontal | 0.0005 mm | | -0.0500 mm | 0.0500 mm | 0 | R | |
| | Vertical | 0.0056 mm | | -0.0500 mm | 0.0500 mm | 0 | R | |
| PMZR RMS | Horizontal | 0.0176 mm | | 0.0000 mm | 0.0500 mm | 0 | R | |
| | Vertical | 0.0313 mm | | 0.0000 mm | 0.0650 mm | 0 | R | |
| INH3 Sigma | Horizontal | 73.6 µm | | 65.0 µm | 80.0 µm | 0 | R | |
| | Vertical | <mark>87.5 μm</mark> | | 75.0 µm | 95.0 µm | 0 | R | |
| INH3 Center | Horizontal | 11243 µm | | 11140 µm | 11325 µm | 0 | R | |
| | Vertical | 5282 µm | | 5050 µm | 5350 µm | 0 | R | |
| INH9 Sigma | Horizontal | 66.8 µm | | 45.0 µm | 70.0 µm | 0 | R | |
| | Vertical | 53.8 μm | | 45.0 µm | 70.0 µm | 0 | R | |
| INH9 Center | Horizontal | 2818 µm | | 2600 µm | 2850 µm | 0 | R | |
| | Vertical | 3444 µm | | 3400 µm | 3550 µm | 0 | R | |
| opUp Oper | ational Mode | TopUp | | Normal | + | 0 | R | |
| M | aster Status | TopUp Automatic ON | | oUp Automatic C | + | 0 | R | |
| | Interlock | inactive | | active | + | 0 | R | |
|)s unlocked | | unlocked | | - | + | 0 | R | |
| opUp System 1 | Efficiency | 0.963 | | 0.680 | 1.100 | 0 | R | |
| | Average | 0.959 | | 0.900 | 1.100 | 0 | R | |
| opUp System 2 | Efficiency | 0.962 | | 0.680 | 1.100 | 0 | R | |
| | Average | 0.958 | | 0.900 | 1.100 | 0 | R | |

• Several correlation configurations of diverse signals over time (shift, day, week or month) are available.

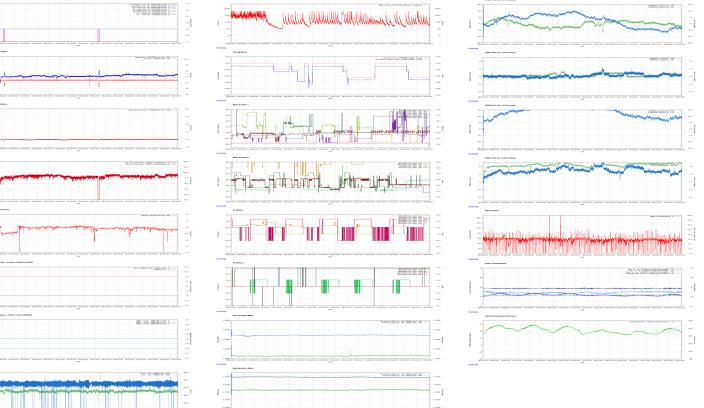
Availability

Outages

MTBF

MTTR

- A correlation overview is a set of plots created from archived data.
- Discussing a list of pre-configured plots of important parameters is part of formal shift handover procedure.
- Identical time-axes ease correlation of concurrent changes and aid identification of causes.
- Slow drifts can be recognized before an alarming state is reached.



RESULTS

Extraction of information with strategic relevance still require combination and correlation of information in all available data stores. At BESSY this is still a "manual" iterative process of presentation, analysis and discussions. Significant steps visible in cumulative primary failure graphics plotted according to root causes have been worked on e.g. with a refurbishment campaign of all quadrupole power supplies, improved diagnostics aiming at kicker misfiring or changed RF maintenance procedures. No appropriate software based, automatic data mining approach could be found so far.

SUMMARY

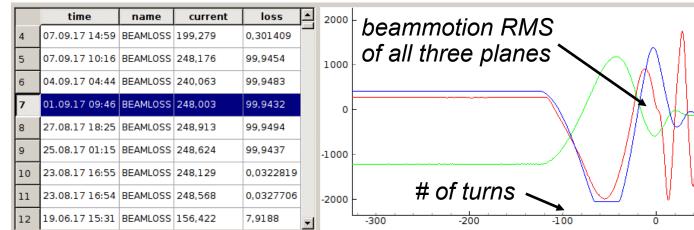
Post-Mortem

Bunch-by-bunch Feedback

- Analysis of turn-by-turn beam motion data of the last few hundred turns hints at the cause of a beamloss:
 - 1-5 turns \rightarrow single kicker firing
 - ~100 turns → RF failure or interlock enforced switch-off
 - 100s of turns \rightarrow e.g. power-supply failure
- Beamloss-relevant data stored in event database together with other relevant data.

Fast Orbit Feedback

• Operates at 150Hz.

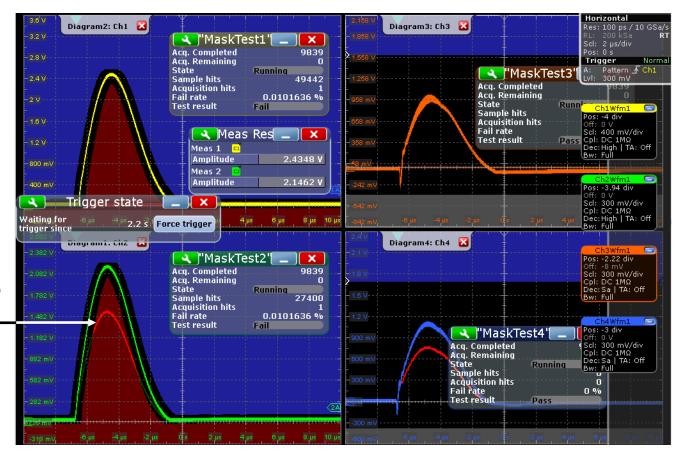


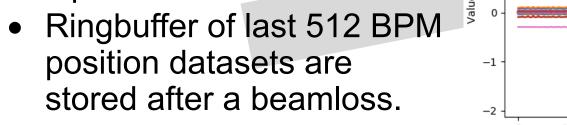
Root cause analysis of failures is the key to mitigation, prevention and repair!

> Kicker fired second time right after injection.

Kicker Pulse Monitor

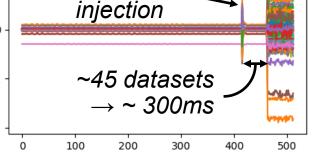
- Records shape of every single kicker pulse of the two storage-ring kickers.
- Any violation of allowed pulse-shape-"corridor" issues an alarm and triggers screenshot of scope.





Logging and Alarm Handling

tions via text messages on mobile devices



• Operator actions and findings are documented in appropriate electronic logbook entries

• Primary monitoring is provided by alarm handlers with logging, beeping, blinking and notifica-

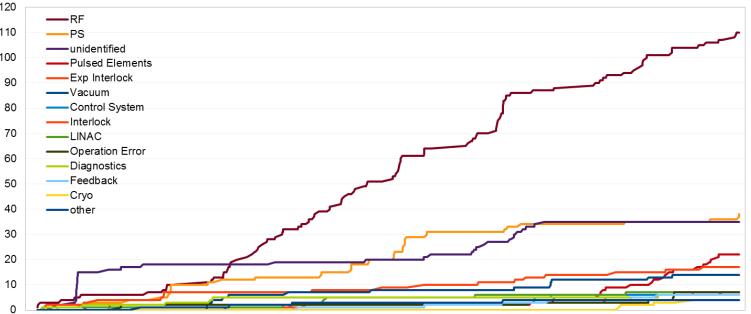
BPM data after

beamloss (noise)

BPM data

during top-up

Wasn't even fully recharged yet.



For long term operational light source facilities like BESSY II transparent availability analysis and maintenance are crucial. Potential users as well as regular customers need to know how the facility of their choice handles disaster prevention and recovery. And management has to know if the preservation and modernization activities are adequate or need readjustment.

As a result of the analysis and tuning tools developed at BESSY there has been practically no beam loss for "unkown reasons" within the last years.

[1] A. Luedeke, M. Bieler, R.H.A. Farias, S. Krecic, R. Mueller, M. Pont, and M. Takao, Common operation metrics for storage ring light sources, Phys. Rev. Accel. Beams 19, 082802
 [2] R. Müller et al., Pseudo Single Bunch Qualities added to Short Pulse Operation of BESSY II, Proc. IPAC17, Copenhagen, Denmark, (2017)
 [3] R. Müller et al., BESSY II Supports an Extensive Suite of Timing Experiments, Proc. IPAC 2016, Busan, Korea, (2016), paper WEPOW011, pp. 2811-2814.

http://accelconf.web. cern.ch/AccelConf/ipac2016/papers/wepow011.pdf

[4] K. Holldack et al., Single bunch X-ray puses on demand from a multi-bunch synchrotron radiation source, Nature Communications 5 (2014), p. 4010/1-7 http://dx.doi.org/10.1038/ncomms5010 [5] J. Feikes et al., Sub-Picosecond Electron Bunches in the BESSY Storage Ring, Proc. EPAC 2004, Lucerne, Switzerland (2004).

[6] Availability tab at http://www-csr.bessy.de/opi/statusm.html, index at http://www-csr.bessy.de/opi/

• Semi-automatic production of failure statistic by component class

• Logs can be browsed with pre-configured or manual queries

past: cmlog — present: Splunk® — future: Elastic Stack

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