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# Reliability in the LCLS Era at SLAC*

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*Abstract*

LCLS hardware availability has been above 90% for the first two commissioning runs of the accelerator. In this paper we compare the reliability data for LCLS (availability, MTBF and MTTR) to those of PEP-II, the $e^+e^-$ collider operating previously at SLAC. It may be seen that the linac availability is not significantly different now than it was before, whhile the availability of the whole LCLS facility is significantly higher than that of the PEP-II facility as a whole (which was about 87%). Most of the improvement is in the MTTR. Ways to improve availability towards the goal of 95% are discussed.

## INTRODUCTION

For LCLS operation,[1] an availability of 95% of the scheduled operating time is being aimed for, in line with the performance of ring light sources. LCLS reliability data i sgathered and analyzed by a computerized database system (CATER) into which every event causing downtime is logged and assigned a system category. Downtime for each event is logged as well as the eventual repair and resolution of the problem. Because of the typical duration of an experiment at LCLS, repair days are scheduled about once per week to address impending failures before they cause unscheduled down time.

## UPTIME DATA

Uptime data for LCLS are shown in Fig 1 for the two dedicated LCLS commissioning periods since mid-April 2008. The average availability is 90.5% for the first period, 91.4% for the second period. Note that this data covers hardware availability only since up to now no user running has been done. Hardware availability is defined as all hardware systems being up and in principle ready for beam (there may be other reasons why no beam is actually being produced).

For comparison, Fig 2 shows the hardware availability for PEP-II during a mature running period, 2005–2008, on a weekly basis.[3] The average availability was 87%. The graph shows several deep dips, indicating significant hardware problems causing extended downtime.

It is instructive to compare the availability data by system, inasmuch as they are comparable, as shown in table 1. LCLS availability is dramatically higher for (magnet-) power supplies and for the rf system, while it is equally dramatically lower for the Controls & Diagnostics area. In case of the power supplies this is directly connected to the

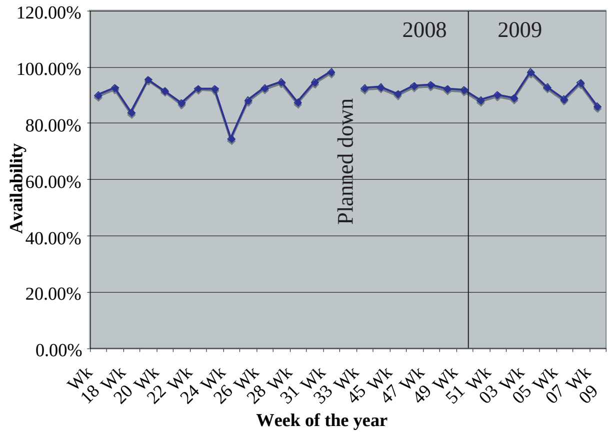


Figure 1: LCLS hardware availability 2008-2009

comparatively small installed total power in LCLS. There are no large chopper supplies in LCLS (these caused significant downtime in PEP-II), and the number of intermediate power supplies in LCLS is much smaller than in PEP-II. The rf system of PEP-II had a relatively high trip rate and long repair times due to the high power and heavy beam loading involved. The PEP-II magnets had a rather unusually high failure rate, also, a number of difficult-to-repair magnets in the Linac are not used for LCLS, as aren't the damping rings. As a result, LCLS has not had any magnet faiures up to the date of this writing. In case of the Utilities; which include the AC distribution system, the availability during PEP-II running was lower in part because of the sensitivity of the PEP-II rf system to glitches in the AC line voltage, which could easily cause significant recovery effort.

The LCLS controls have significant less availability than

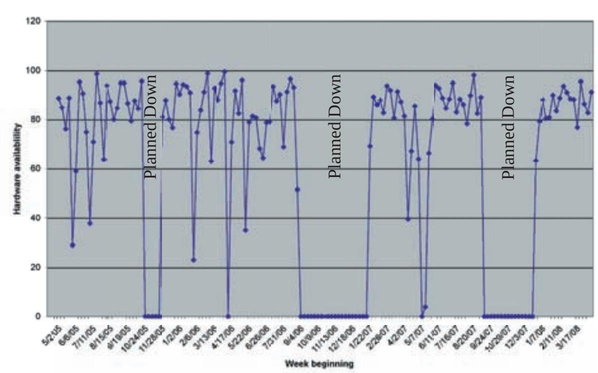


Figure 2: PEP-II hardware availability 2005–2008

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Table 1: Comparison of PEP-II and LCLS availability for selected systems.

| System | PEP-II (%) | LCLS (%) |
|---|---|---|
| Power Supplies | 96.4 | 99.25 |
| Magnets | 99.25 | 100.0 |
| Rf System | 97.92 | 99.01 |
| Vacuum Systemn | 98.20 | 99.40 |
| Utilities | 97.50 | 98.79 |
| Guns, Lasers | – | – |
| Controls & Diag. | 98.00 | 95.90 |
| non-rad Safety | – | – |
| Alignment | – | – |
| Other | – | – |
| Unassigned | – | – |

for PEP-II. This goes to a certain extent to the account of the radiation safety systems (Beam Containment System [BCS] and Personnel Protection System [PPS]), which had a number of teething problems during the LCLS startup. Another detriment in LCLS is the considerable amount of new hardware (EPICS IOCs) and software that require debugging, whereas the PEP-II running period considered here covers a state of mature running with the control system fully debugged and commissioned.

### *Uptime Goals*

For the LCLS, an uptime goal of 95% has been stated [2]. While the data so far indicate that we are not too far away, there remains essentially a factor of 2 improvement necessary to meet this goal. One of the challenges is the apportionement of this goal by system. Since the different systems vary in size and in complexity one cannot require identical performance for each. For LCLS we are trying out a set of goals derived from the 2008-run data. For that commissioning run, availability for each system was analysed on a week-by-week basis. Then, the two weeks with the worst performance for each system were subtracted from the data set and availability recalculated. With this reduced set the availability reached 95%. In this way, for each system a reliability goal was established, and this formalism in a natural way put less stringent requirements on e.g. the controls and beam-diagnostics systems as a whole, while inherently reliable systems like vacuum and power supplies face tougher, but achievable, goals. Table 2 shows the goals derived by this analysis. This mechanism does inherently assume statistical relevance of the data the goals are based on, an assumption that may well be questioned. However, by periodically reviewing and adjusting the availability goals they will stay relevant to the actual running experience.

This formalism identified a limited set of failures, the prevention of recurrence of which could (in theory) raise the facility availability to 95% and above. Each maintenance group analysed these events, and mitigation actions were taken where practical. In several cases this led to actions implemented, in some cases the required action would be significant upgrades that need to be funded through AIPs and therefore have a longer lead time.

Table 2: LCLS Availability Goals

| System | Availability (%) | Goal (%) |
|---|---|---|
| Power Supplies | 98.33 | 99.41 |
| Magnets | 100.0 | 99.99 |
| Rf System | 97.78 | 98.69 |
| Vacuum Systemn | 99.13 | 99.86 |
| Utilities | 98.53 | 99.31 |
| Guns, Lasers | 98.81 | 99.33 |
| Controls & Diag. | 96.42 | 98.37 |
| non-rad Safety | 100.0 | 99.99 |
| Alignment | 100.0 | 99.99 |
| Other | 100.0 | 99.99 |
| Unassigned | 100.0 | 99.99 |
| **Total** | 90.5 | 95.0 |

Note: 100.0% Availability means no downtime recorded for system. These were ascribed a goal of 99.99%. Since the 2008 data were recorded using the old catogorization, the data were manually redistributed to the new catogorization scheme in effect since the 2008-2009 commissioning run.

### *System categories*

For LCLS, the categories used were reviewed and modified to reflect the change in the facility after the turn-off of PEP-II. Also, in this modification an attempt was made to re-align the categories with the groups doing the actual work. I.e., modulators and power supplies in the linac rf system are being maintained by the Power Electronics group and not the rf group, consequently they are now treated as a subcategory of “Power Supplies” rather then “Rf”. In this way we are now tracking 11 major cagtegories with each of them having several subcategories. A special case is Controls, which has a large and diverse area of responsibility requiring a third level of detail.

## MTBF AND MTTR

We use the following definitions for mean time between failure (MTBF) and mean time to repair (MTTR):

$$\mathrm{MTBF} = \frac{\sum t_{sch}}{\#\mathrm{events}}, \;\; \text{and } \mathrm{MTTR} = \frac{\sum t_{down}}{\#\mathrm{events}}$$

where $t_{sch}$ is the scheduled operating time and $t_{down}$, the unscheduled down time. #events is the number of discrete failure events during $t_{sch}$. The LCLS MTBF for the time frame covered in Fig. 1 is 14.6 hours while the MTTR is 1.2 hours. This may be compared to the PEP-II MTBF across all 7 runs of 17.1 hours, with an MTTR of 2.5 hours.[3]

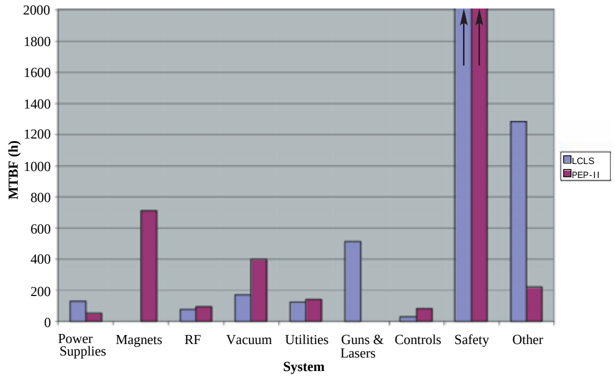


Figure 3: LCLS and PEP-II MTBF by system

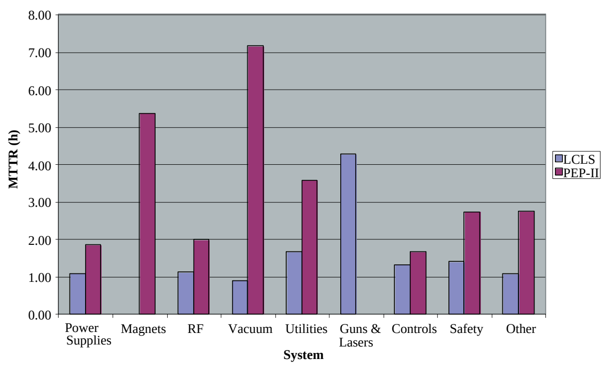


Figure 4: LCLS and PEP-II MTTR by system

Fig. 3 shows the MTBF for LCLS and PEP-II, by system and Fig. 4, the MTTR. For LCLS, most systems have shorter MTTR that for PEP-II, which indicates either less complexity of the LCLS systems or more efficient repair (most likely the former). Particularly striking is the short (1 h) MTTR compared to PEP-II (7 h) for the vacuum system. This directly reflects the often long-duration vacuum repairs in PEP-II (several shifts when replacement of a component was necessary), whereas in LCLS the vacuum system is not as much stressed and consequently we did not have particularly difficult repairs yet. For power supplies, the shorter MTTR while longer MTBF directly reflects the much better uptime of the system compared to PEP-II. The similar numbers for Controls for LCLS and PEP-II are surprising as they do not seem to reflect the much poorer performance for LCLS compared to PEP-II. For magnets, there is no LCLS data for a lack of magnet failiures while for Guns & lasers we have no useable PEP-II data, in part because PEP-II tended to bridge gun outages by coasting the stored beam.

### *Interpretation*

The first rather striking observation is that the improvement in availability for LCLS as compared to PEP-II cannot be credited to lower failure rates, but rather to a faster turn-around in repairing faults. This is at first sight surprising: The PEP-II complex encompassed 3 km of Linac plus $2\times2$ km of PEP-II storage ring, plus two damping rings (a major source of problems) and injection beam transport, for a total linear length of at least 7 km of accelerator and beam line. LCLS has 1 km of linac plus about another 1 km of beam line and undulator ("Undulator Complex"). Just from the reduced size and complexity of the LCLS facility one would have expected higher reliability numbers.

Simple scaling with the length of accelerator turns out not to be a good measure, however, for the following reasons:

- PEP-II operation was actually not fully dependent on linac uptime: failures in the linac could be "coasted through" by the PEP-II rings just storing the beam, thus linac outages would not show up in the statistics unless they exceeded the coasting time. Therefore PEP-II availability was better than the combination of linac and PEP-II proper availability would suggest.
- The PEP-II data included here represent a mature facility while LCLS is still being commissioned; "infant mortalities" can be expected to reduce LCLS availability.

The effect stated in the first bullet is quite significant. In fact, the availability of linac and damping rings together was quite a bit lower than the LCLS linac availability, but masked by PEP-II coasting operation. On the other hand, there is evidence of "infant mortality" in the LCLS: After the year-end break, when the Undulator Complex began commissioning operation, the availability of the Controls area suffered greatly, mostly due to teething problems with the safety systems. This had significant impact on the machine uptime, which would otherwise have been at least one %-point above the actual numbers.

Improvement of the availability of LCLS will come from a number of sources:

- As commissioning is progressing, early failures esp. in Controls are being addressed and we expect an upward trend in availability for Controls as the system matures.
- We continue to address the failures causing significant downtimes in a more strategic way beyond the immediate repair. Examples of this approach include
  - proactively cleaning electronic boards & increasing the frequency of air filter changes,
  - reconfiguring power supply areas for quicker exchange and staging of spares,
  - reconfiguring of timing distribution to minimize impact of shifts in certain timing chassis,
  - etc.

## REFERENCES

[1] P. Emma, this conference.

[2] J. Galayda, priv. communication

[3] *see also* R. Erickson et al., Proc. $23^{rd}$ Advanced ICFA Beam Dynamics Workshop on High-Luminosity $e^+e^-$ Colliders, Ithaca, NY, 2001.