Power Supply Reliability Improvements

ASD Power Systems Group

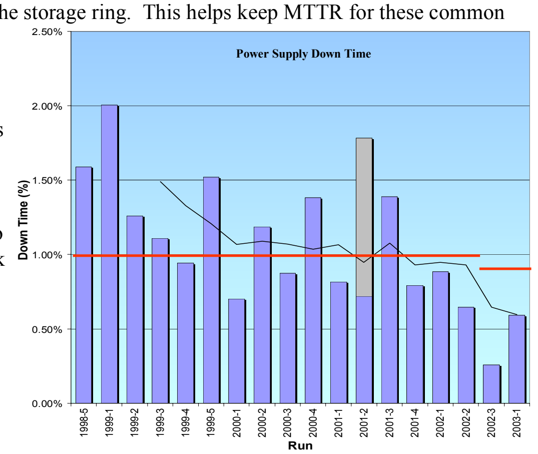
Measures of Reliability

ASD Power Systems Group measures power supply reliability in a number of ways. Among these, the two most meaningful measures to the APS users are down time and fault rate. While down time can be addressed to a certain extent by reducing Mean Time To Repair (MTTR), fault rate cannot. It requires a robust design, quality workmanship, and preventative maintenance in order to achieve high reliability.

Reducing Down Time

The chart below shows that we have consistently met our down time budget of 0.9% (changed from 1% in FY2003) since the beginning of FY2002 and the trend line shows the improvements over the past year.

We have a program in place to train and certify control room operators to replace failed power converters in the storage ring. This helps keep MTTR for these common failures to a minimum.

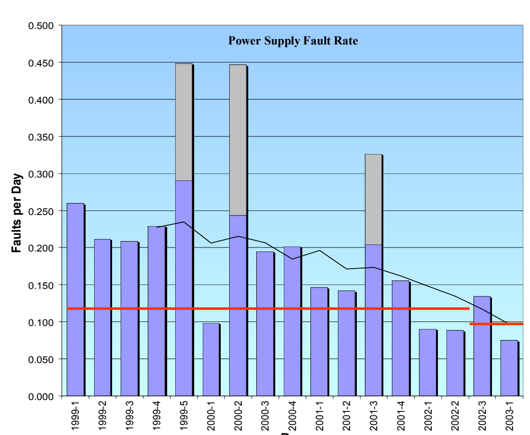


Of course, a single major failure can still cause a great deal of down time as shown on the chart to the right. The portion of down time for run 2001-2 indicated in gray was due to a single event – a water leak developed in a booster extraction septum power supply. The problem went unnoticed long enough for the water to leak through a penetration into the tunnel and caused damage to the magnet. This event alone resulted in 13.2 hours of down time.

Even though we can improve down time by reducing MTTR, a much more effective approach is to eliminate the faults from occurring in the first place, *i.e.,* reduce fault rate.

Reducing Fault Rate

Reducing fault rate, which is the inverse of Mean Time Between Failures (MTBF), has been a more challenging goal for us to meet. The APS has nearly 1500 power supplies in the storage ring alone which makes it somewhat unique with respect to other high-energy light sources†. A failure in any one of these can potentially bring down beam, so reducing fault rate requires a very high reliability from each individual power converter.



At the beginning of run 2002-3, our fault rate goal was changed from 0.12 faults per day to 0.1 faults per day corresponding to a MTBF of 240 hours.

The chart to the left indicates that we have had some success in recent runs, however we are not yet consistently meeting our goal, so there is room for improvement. Our efforts are focused on reducing fault rate by maintaining a robust design, quality workmanship, and proactive preventative maintenance.

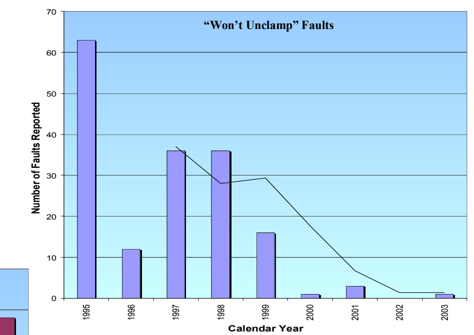
Outliers, indicated in gray on the chart, are the result of the following:

- Run 1999-5: Glitching power supply that was difficult to identify.
- Run 2000-2: Software limit removed inadvertently.
- Run 2001-3: Incorrect diagnosis in conjunction with reset policy at the time.

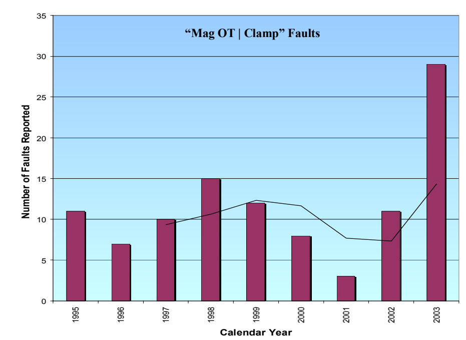
Maintaining a Robust Design

A robust design requires more than just good engineering practices up front. It also requires a thorough understanding of potential and common failure modes so the right improvements and upgrades can be made.

We periodically analyze our fault information looking for improvements we can make that will have the biggest impact.



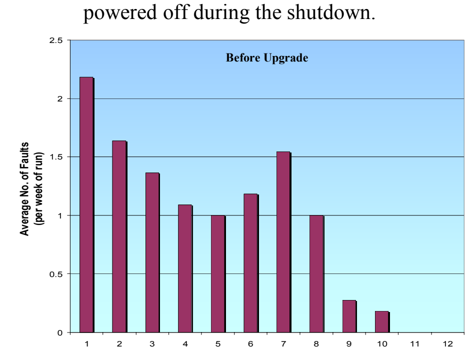
For example, the chart on the right shows a common failure we had early on that prevented the power converters from unclamping. The cause of this failure was identified and a modification was made to the electronic cards that has virtually eliminated this problem.



By contrast, the chart on the left shows a recent increase in "Mag OT | Clamp" faults. The cause of this we believe is simply that we have been documenting more of these faults when they occur during startup testing or studies periods, but this is something we will be investigating further to confirm.

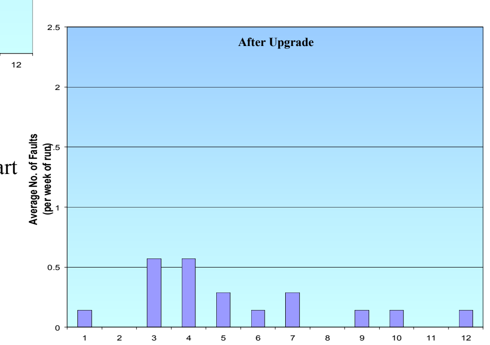
Example: Control Power Upgrade

The control power upgrade is a perfect example of how we have put our fault analysis to good use. The chart to the left below indicates that we used to see a large percentage of our faults in the weeks immediately following a shutdown. The majority of these faults were failures in the control power assemblies and related circuits after being powered off during the shutdown.



Over a period of about a year and a half, we upgraded all of the storage ring power converters with new control power assemblies. The new assemblies do not require water for cooling, so we were also able to reconfigure the power feed allowing us to keep control power on to all the supplies during the shutdown.

This has resulted in a significant reduction in number of faults at start up. You can clearly see the results in the chart to the right.

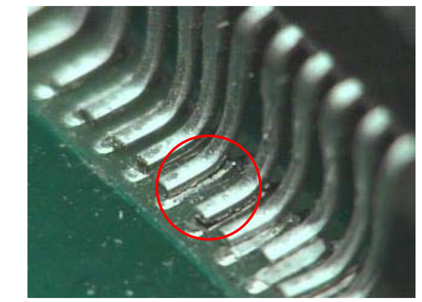


With such a large number of power supplies, implementation alone of upgrades and modifications presents its own challenges. We have to ensure that we don't introduce new problems as we did in run 2000-2 when we made a software upgrade to provide new diagnostics to identify glitching power supplies. At the same time, we inadvertently removed a software limit that caused several beam trips to occur. The problem was quickly identified and resolved, but the damage had already been done. One way we reduce the risk of introducing new problems is by developing a quality control program.

Quality Workmanship

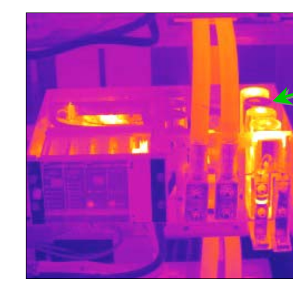
There are probably upwards of a billion solder connections in the power supplies and supporting electronics that make up the APS storage ring. Interestingly, a defective solder connection can work fine for years and suddenly begin to fail intermittently making it extremely difficult to troubleshoot.

As part of our quality control program, we have recently adopted the industry accepted IPC-A-610C standard for Acceptability of Electronic Assemblies. Our entire group has been trained and certified by IPC to inspect electronic assemblies to this standard. Not only do we require this level of workmanship for in-house work, but outside vendors are required to meet this standard as well.

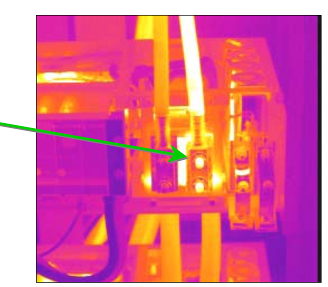


Proactive Preventative Maintenance

We are also working to refine our preventative maintenance plan with the goal of identifying and repairing problems during scheduled maintenance periods before they become severe enough to cause down time. One technique we employ is routine thermal imaging.



Failed capacitor running cooler than the others in a storage ring power supply. The supply will operate in this condition, but it causes undue stress on the other capacitors and they will eventually fail causing a fault.



Loose magnet cable connection causing excessive heat in lugs and cable.

Future Plans

We believe that we have a good plan and the data appears to indicate it is working – fault rate and down time are dropping, and we are systematically eliminating entire failure modes. We intend to continue this approach with, among others, the following efforts:

Maintaining a Robust Design

- Redesign kicker supplies to reduce stress on high voltage cables.
- Replace Power Supply Control Units to reduce interconnect related failures and eliminate component obsolescence issues.

Quality Workmanship

- Implement code reviews and software inspections.
- Expand test capabilities such as thermal cycling of new circuit cards in order to identify bad solder connections before installation.

Preventative Maintenance

- Refine and adopt a more rigid maintenance schedule as well as trending power converter temperatures to find potential problems.

† SPring-8 and ESRF have approximately 10 supplies driving multipole magnets where APS has over 800.

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