ACCELERATOR AVAILABILITY AND RELIABILITY ISSUES*

S. Suhring, Jefferson Lab, Newport News, VA 23606, USA

Abstract

Maintaining reliable machine operations for existing machines as well as planning for future machines' operability present significant challenges to those responsible for system performance and improvement. Changes to machine requirements and beam specifications often reduce overall machine availability in an effort to meet user needs. Accelerator reliability issues from around the world will be presented, followed by a discussion of the major factors influencing machine availability.

INTRODUCTION

"*The people at the other end of the machine must be happy.*" This quote by Hamid Aït Abderrahim [1] of the Centre d'Etude de l'Energie Nucléaire is both broad and true. No matter which large accelerator one considers—from synchrotron light sources, which have many dozens of simultaneous, short-run users, to high energy machines like Fermi's Tevatron with experiments that run for years, to recirculating CW superconducting machines like Jefferson Lab's electron accelerator, to machines presently under construction like the Spallation Neutron Source—happy people are the result of machine performance at a level that satisfies all of the affiliated parties.

Machines are built with a number of specific goals in mind, of which availability is just one. Other goals such as energy, luminosity, number of users, and throughput of research are just as likely to be sacrificed once the reality of operation settles in. For an experimentalist, beam energy might be sacrificed in order to keep the integrated beam delivery time / luminosity high. For a lab manager with a limited budget, beam time might be sacrificed to reduce power bills, maintenance deferred to lengthen machine run time, or spare parts inventories depleted. For the technical staff, documentation and system performance may never reach the intended level of excellence.

This paper will look at some of the common issues that affect the availability of existing large machines, and it may serve to help future projects in their planning, design, construction, and commissioning.

RECORD KEEPING

"A major difference between a 'well developed' science such as physics and some of the less 'well developed' sciences such as psychology or sociology is the degree to which things are measured." Fred S. Roberts [2]

Accurate record keeping of problems that interfere with beam delivery is central to keeping a machine operating well and making improvements to performance. These records should be started at the beginning of the commissioning stage and should be made available to anyone interested in the information. The machine operations group is the logical choice for record keeping and high-level analysis of lost time events. Recording a problem should be easy, and each event description should include actual times, duration, system, component, cause, and additional comments describing the event in detail.

Of course, some of this information may be incorrect as initially recorded, so a filtering of the information should take place. Such filtering should be done by a knowledgeable staff member who is familiar with all aspects of the machine and who has reasonable negotiating skills so that allocation of lost time can be fairly attributed. System owners should also be able to check regularly on their own system's lost time so that if corrections to the records are needed, they can be made.

The approach taken at Jefferson Lab is to record any and all system failures. This method is not universally used at other labs. JLab's philosophy is to keep 'luck' from entering into the discussion. If a system is down and another component fails, then both items have lost time recorded. This approach to lost time bookkeeping should not be confused with the Department of Energy contract metrics for beam delivery. The first identifies breakdowns or unacceptable performance; the second revolves around beam delivery time accounting. By recording all failures, honest assessments of overall system performance can be made and used for resource allocation decisions.

Early efforts to combine downtime information from laboratories around the world took place in the mid 1990s. [3] This attempt at data compilation was done to improve information exchange and to aid in the design effort of proposed machines. RAM (Reliability, Availability, Maintainability) studies were commonly discussed and to a lesser level still are. [4] However, projected performance of future machines based on an extrapolation of existing machine reliability has certain inherent flaws. Most importantly, the amount of data available is insufficient to make availability estimates. [5] Also, the generalization of system performance doesn't often overlay with the exotic nature and size of new machines. The revitalization of a worldwide reliability database is recognized as an important activity, and efforts are underway at the European Synchrotron Radiation Facility (ESRF) to develop just such a resource. [6]

Reliability theory relies on sound mathematical processes where Mean Time Between Failure (MTBF) and other terms can be measured, manipulated, plotted, and studied. [7] A typical visual representation of reliability theory is the bathtub curve, wherein a

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component will have a high number of failures early in its life (startup problems or infant mortality), settle into a much lower failure rate during its useful lifetime, and then, near the end of its useful life, the component group will begin to degrade (see Figure 1).

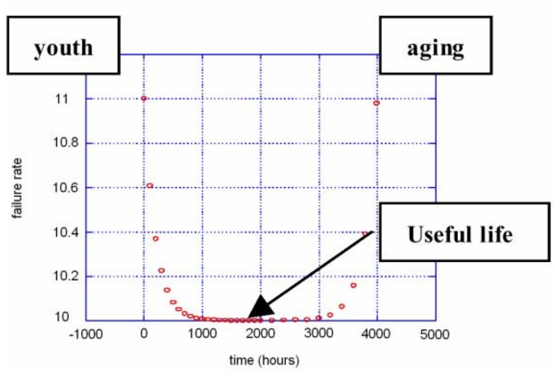

Figure 1: Bathtub curve.

The complexity of modern machines with hundreds of klystrons, thousands of magnets, tens of thousands of cable connections, and hundreds of thousands of control points does not easily allow for in-depth mathematical analysis for improving machine performance.

PRACTICAL RELIABILITY

"In a linear collider, all systems from injectors to beam dumps must be fully operational on every pulse."
ILC-TRC [8]

Who in our field would wait for a large enough statistical sample of failures before deciding on a course of action to improve the system in question? One failure is a point event. Two points imply a trend. By the time a problem occurs for a third time, the trend is well established and will not go away. The RF system engineers at Paul Scherrer Institut (PSI) analyze each and every failure. [9] This requires a significant investment, both in people's time and in data acquisition tools, but it has allowed PSI to quickly respond to problems and raise the reliability of their RF system to extraordinary levels.

Another means for improving reliability is to build enough redundancy into the system so that a certain number of failures do not interfere with machine performance. Experience has shown that when additional RF overhead is available, experimentalists will lobby for higher energy. This puts machine availability in jeopardy. It also highlights the difficult decisions that are made when trying to meet the needs of a user community.

There is no equation that can be used to calculate the risk/benefit ratio for the institutional decision to push a machine to higher performance goals. Often the opposite is true: performance goals are relaxed in order to allow for more stable machine operation. [10]

COMMON PROBLEMS

"There are a large number of things that can go wrong."
Roger Erickson [11]

If we begin to look at common problems among machines worldwide, a number of similarities emerge, not all of which can be discussed in this publication.

Water

Whether it be frozen pipes [12, 13], blocked flow [14, 15], failed hoses [16], erosion of fittings [17], or the interaction of dissimilar metals [18], water and its handling rank high among 'simple' systems that are a major source of lost time. Low Conductivity Water (LCW) and Deionized Water (DI) are often used interchangeably, and for this paper the distinction is unimportant.

If a perfect water system were to be designed, it would meet the specifications needed to provide adequate cooling, have redundancy in its pumps, and have the necessary monitoring to anticipate failures. And it would work from the start. The diabolical aspect of LCW problems is that they are often unseen until too late.

As an example, the original LCW plant at Jefferson Lab was constructed with iron body pumps and steel feed tanks. It operated without conductivity controls, relying on a 10% side stream through DI bottles. It operated for ~1 year before magnets began to overheat due to clogged coils. Samples were taken, and large concentrations of iron oxides were found. Conductivity monitoring and controls were installed and the iron/steel components replaced with stainless steel. Set points of 2 MΩ, 95°F ±0.5°F were established for the two 2000 gpm systems.

Eight years later, the magnets again began to overheat due to clogged coils. The sample analysis indicated copper oxides. The source? Oxygen levels within the water system were at their worst possible levels (~200 ppb) and were reacting with the copper cooling coils (see Figure 2). [19]

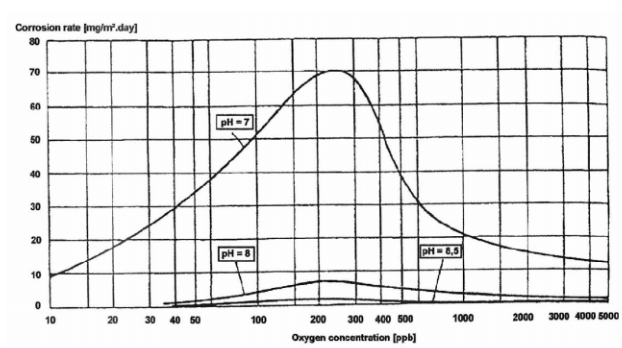

Fig. 2: Influence of dissolved oxygen on copper release rate. [20]

The solution? Installation of a de-oxygenation system to bring the concentration down to <10 ppb, full flow 0.5 micron filters, and hot citric acid etching and water flushing of the magnet coils to remove any built up material. Additionally, LCW system entry procedures were revised to require significant flushing and purging of all air prior to returning to normal flow circulation.

Buildings

"Infrastructure, although of minor importance in scientific minds, plays a non-negligible role . . ." Managing Science [21]

In machine enclosures and their service buildings, the lighting should be of high quality to promote good quality work. Furthermore, buildings should be equipped with air conditioning. This might be considered an extravagance, but when viewed as a reliable method of controlling the largest sources of premature electronics failure—heat, humidity, and dust—air conditioning becomes a necessity. Also, improved work conditions foster better quality technician performance, especially during the installation and commissioning stage of projects. Retrofitting buildings for air conditioning can be difficult. Conduit, cable trays, fire headers, and cooling water lines may limit air distribution options.

Electricity

Budget considerations and machine performance goals figure prominently when considering site power. The ~6 M€ capital outlay at ESRF resulted in an increase in availability from 95% to 98% with the installation of 10 1 MVA diesel engines and their associated controls, switches, and conditioners. [22] In addition to providing a more regular source of electricity, damage to equipment from power interruptions was greatly reduced.

If a real time backup power system isn't part of a power plan, then multiple power feeds onto a site will provide a quick means of restoring necessary services in the event of a supply problem. Finally, a robust site power distribution plan is incomplete unless the electrical substations are on loops that allow for "make before break" switching of feeds.

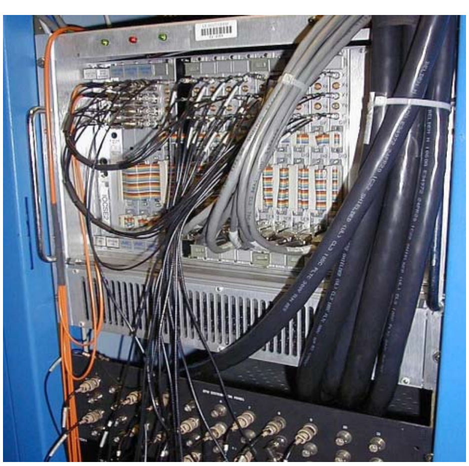

Figure 3: Filter and fan trays obstructed by cables.

Fans, Filters, and Cables

On a smaller scale, other seemingly simple items that have caused significant lost time are fans, filters and cables. Crate filters require periodic cleaning and small fans fail after 3–4 years. Problems arise when components are not easily serviced. With real estate in electronics racks at a premium, the tendency is to make designs as compact as possible, sometimes to the detriment of serviceability. Poor cable runs or the need to otherwise disassemble equipment may impede routine maintenance. There is the potential to create new problems by simply disturbing the equipment. [23] Sufficient rack space and selection of maintainable equipment is important to being able to keep systems operational (see Figure 3).

Electronics

At the board level, consideration should be given to the use of chip, trim, and low temperature coefficient precision resistors [24] where small magnet power supply regulation is crucial. Board standardization and interchangeability can significantly improve machine reproducibility and reduce set up time. JLab corrector magnet power supplies all regulate to ±2 mA (see Figure 4).

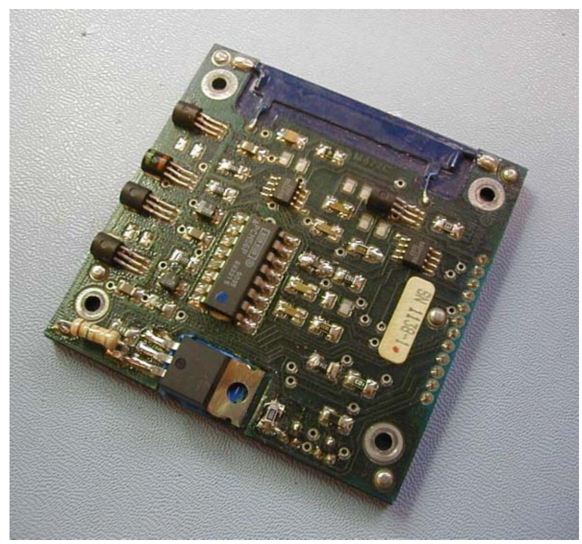

Figure 4: Analog block layout.

Software

Though component selection plays a large role in machine performance, understanding and controlling the devices may be even more critical. Picture a magnet mapping test area. Early in a project, detailed measurements of magnet performance are made. Were the measurements made using the machine's power supplies and control software? Was the hysteresis protocol even known when the mapping took place? Will the control system used to run the mapping test stand have the same timing and sequencing as the operational machine? Will the magnetic field in the test stand be the same as that seen by the beam? The answers to these questions will in large part determine the time it takes to set up machines that require frequent energy changes.

Other software issues such as file management, speed (control system response time), and channel access security seem to be so integrally meshed with hardware that they are especially difficult to assess when problems arise. If the focus of machine availability were solely on hardware, then components could be designed toward perfection. Software has interdependencies between programs, applications, signals, and displays and is of such importance to operations that well regulated version controls are essential to machine availability. Test plan implementation should include roll back or back out procedures that are quick, clean, and well documented. High Level Applications involving energy, phase, and beam position are so closely interconnected that it can be difficult to assess problems in beam stability that result from the interaction of feedback loops.

Commissioning

Long-term machine performance can be enhanced with early beam commissioning tests. These studies can help identify design flaws and weed out component problems. Furthermore, the startup period can be used to develop procedures for safe, efficient operations. [25] A staged commissioning plan may require temporary radiation shielding walls and access control equipment. It may also need to address life safety issues of egress. But early beam-based tests provide an opportunity to develop a conduct-of-operations protocol, train operators and support staff, get documentation in order, and test software applications.

Machine Tuning

Machine setup and tuning is scheduled following planned shutdowns and maintenance periods. But when equipment or software is underperforming, lost time from tuning can be significant. Diagnostic tools to check equipment, control system performance, and beam quality will play prominently in identification of system degradation. Monitoring tools are often integrally linked to the beam—identifying a problem might rely on the components causing the problem. Tune time, like other interruptions to beam delivery, should be tracked, analyzed, and acted upon, leading to improved availability.

CONCLUSION

"It is a true wonder that they run at all."
Sture Hultqvist [26]

Our machines run quite well, considering the complexity of the systems and the demands placed upon them by the user community. Hardware availabilities of 70%–90% have been reached at large energy frontier machines and as high as >98% at synchrotron light sources. [27]

The lost time that is more difficult to address is the single, large, unrelated, unexpected event. The stories are the stuff of legends—bizarre vacuum events, animals in transformers, flashlights inadvertently left in beam lines. These problems are rarely repeat offenders, and if they had been anticipated, would not have happened. Probability trees and system failure predictions rarely take the inconceivable into account, but these events often cause significant interruption to a program. It is at just such times that the focus of a laboratory and its creative and talented staff come together to solve the problem and return to more normal availability issues.

With constant attention to detail and dedicated staff, the sources of lost time are avoided by a rigorous design effort, or identified during commissioning and operation. Solutions are implemented as quickly and efficiently as possible.

The major sources of lost time are constantly changing. Today's worst offender can be identified, corrected, and no longer be a significant source of trouble, making way for the next improvement.

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