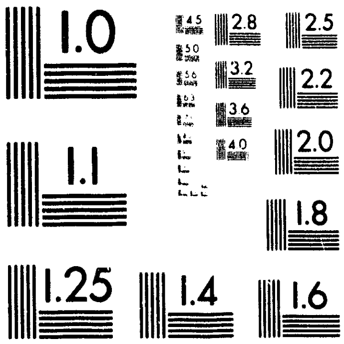
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BASIS FOR THE POWER SUPPLY RELIABILITY STUDY OF THE 1 MW NEUTRON SOURCE

D. G. McGhee and M. Fathizadeh

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439-4814

ABSTRACT

The Intense Pulsed Neutron Source (IPNS) upgrade to 1 MW requires new power supply designs [1]. This paper describes the tools and the methodology needed to assess the reliability of the power supplies. Both the design and operation of the power supplies in the synchrotron will be taken into account. To develop a reliability budget, the experiments to be conducted with this accelerator are reviewed, and data is collected on the number and duration of interruptions possible before an experiment is required to start over. Once the budget is established, several accelerators of this type will be examined. The budget is allocated to the different accelerator systems based on their operating experience. The accelerator data is usually in terms of machine availability and system down time. It takes into account mean time to failure (MTTF), time to diagnose, time to repair or replace the failed components, and time to get the machine back online. These estimated times are used as baselines for the design. Even though we are in the early stage of design, available data can be analyzed to estimate the MTTF for the power supplies.

I. INTRODUCTION

The proposed reliability studies for the IPNS upgrade to 1 MW follow the format outlined during the Advanced Photon Source (APS) Reliability Workshop held at Argonne National Laboratory on January 29-31, 1992. Neutron source users establish a reliability or availability budget based on the number and length of disruptions experiments can sustain without data collection rates going below an acceptable level and 2) the operating experience of existing machines. These studies will concentrate on the reliability tools used for power supply designs: the main resonant magnet circuits and power supplies for the synchrotron of the proposed 1 MW IPNS upgrade. [1]. Based on the chosen budget for the machine, reliability budgets of the contributing subsystems will be determined using previous experience from existing machines, particularly IPNS, as it is and has been operating with a resonant magnet circuit similar to that proposed for the upgrade.

II. APS RELIABILITY WORKSHOP 29-31 JANUARY 1992

A workshop was held at APS to address reliability goals for accelerator systems. Seventy-one individuals participated in the workshop, including 30 from other institutions. The goals of the workshop were to:

1. Give attendees an introduction to the basic concepts of reliability analysis.

2. Exchange information on operating experience at existing accelerator facilities and strategies for achieving reliability at facilities under design or in construction.

3. Discuss reliability goals for the APS and how to attain them.

Data on the reliability of operating electron storage rings should be collected and analyzed to provide a database for more informed quantitative estimates of system reliability and maintainability.

The workshop included a series of lectures by Professors Rice and Hall of the University of Illinois at Chicago and the University of Illinois at Urbana-Champaign, respectively. They introduced mathematical definitions of availability (the fraction of time a system is performing its function as planned) and

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reliability in a time interval T (the probability a system will perform its function without interruption for an interval T). The effect of maintenance on availability and the effect of redundancy on reliability were also discussed.

Representatives from other laboratories presented information on the operating history of other accelerator facilities, e.g. Princeton Plasma Physics Laboratory's (PPPL) fault reporting procedures and the reliability planning activities for the Superconducting Super Collider (SSC), the Relativistic Heavy Ion Collider (RHIC), the Cornell Electron Storage Ring (CESR) B-Factory, and the Stanford Linear Accelerator Center/Lawrence Berkeley Laboratory (SLAC/LBL) B-Factory.

Working group discussions were held to address the following subsystems.

The rf working group felt that the reliability goal could be met. They studied the potential for improvement in availability and its effect on reliability by installing a fourth rf system to function as a "hot spare," should one of the originally planned systems fail. Participants from SLAC reported that this worked well at PEP; it was possible to shut down one rf station without interrupting operation.

The vacuum working group felt that the 99% goal is very difficult to achieve. They identified the potentially long recovery time from a vacuum accident requiring bakeout of the whole storage ring as an area to consider for improvement.

The power supply working group felt that the 99% goal is extremely difficult due to the large number of power supplies in the storage ring. Preemptive maintenance based on sophisticated testing procedures was considered the best approach to the problem.

The interlock and diagnostics working group proposed a conceptual design for the beam abort system, based on turning off the rf power in the storage ring. They stressed two points: first, redundancy to improve the reliability of the interlock function is at odds with overall facility reliability because redundant interlocks can trigger more false alarms; second, the magnitude of beam excursion defined as the beam abort trigger level should be made as large as possible to prevent noise-induced false alarms.

Another working group addressed the cost of unreliability in a synchrotron radiation facility. Several comparisons were made between the availability/reliability requirements of a particle physics accelerator and those of a synchrotron radiation facility. The largely fixed configuration and several-year duration of a high energy physics experiment do not demand very high reliability; the important figure of merit is availability averaged over a year or more. A one-week outage is not very long by these standards.

A synchrotron radiation user will typically be scheduled for 1-2 weeks of beam time to accomplish a specific experiment. About tenfold this amount of time is spent preparing for the experiment beforehand and analyzing data afterward. Even short interruptions near the end of the scheduled beam time might prevent the collection of enough data for a complete, definitive analysis. In this way the entire investment of time in the experiment is lost. Estimates derived from interviews of synchrotron radiation users indicated that even if the facility runs 75% of the time scheduled, experiments would take twice as long to do compared to a perfectly operating facility. This means the cost of research at a facility with 75% availability would be twice that of a 100% available facility.

III. POWER SUPPLIES WORKING GROUP SUMMARY AND CONCLUSION

1) The reliability and availability of the chopper power supplies were calculated. If 99% reliability is needed, the power supply MTTF must be about 900 years which is unrealistic. However, if scheduled maintenance is performed during refill and dumping of the beam, then an availability of 99% is attainable.

2) Most of the problems usually show up within the first two years of operation, and after debugging and improving the system, the reliability improves. Thus, a trial period is required to find and replace most of the components that cause failure of the system.

3) Unexpected problems caused by noise and

voltage transients can cause interruptions. Circuits should be designed and tested for such conditions in order to have more reliable power supplies.

4) Crews must be well-trained, and parts must be modularized for ease of repair.

5) Electronic boards should be tested for effects of vibration on cold solder joints according to Department of Defense procedures.

6) Some parameters of power supplies can be measured in order to anticipate failure. For example, in bipolar transistors, the gain [ß] can be measured at any time in order to predict the failure of the device. These devices should be replaced before failure.

7) Heat cycling should be performed on the electronic boards to speed up the infant mortality period of the devices.

8) When ordering power supplies from a vendor or a manufacturer, all the components should be specified by name and manufacturer.

9) In order to make maintenance safer and easier, buses should be covered.

10) An optimization program for the number of spare components on hand will be performed in order to determine the appropriate number of spare parts for the inventory.

11) Experiences should be shared with other laboratories.

12) Learn from operations, perform diagnostics, monitor signals, and analyze failures. Failure can provide valuable information for future plans.

13) In the design stage of a circuit, reliability analysis should be performed to predict the component or set of components most likely to fail.

IV. AVAILABILITY AND RELIABILITY TOOLS FOR POWER SUPPLY SYSTEMS

The power supply system is a series system with F1, F2, ••• Fn failure modes, where n = the number of modules. For the ring magnet power supplies, dipole and quadrupoles, we consider each resonant cell to be a module. Therefore, we have one series system with 12 modules. Series systems are non-redundant; that is, the failure of any one component will fail the system. At this early stage of design and drawing from Argonne's reliability workshop, we have assumed a failure rate of 1 per 1000 hrs of operation and a repair time of 2 hours per failure. From this, availability of the system is defined as:

$$AVAIL = \frac{SUT - UDT}{SUT}, \qquad (1)$$

$$= 1 - \frac{MTTR}{MTTF}, \qquad (2)$$

$$= 1 - MTTR \times \lambda_S, \qquad (3)$$

$$= 0.998,$$

where SUT is scheduled up time, UDT is unscheduled down time, and MTTR is the mean down time for repair. λ_S is the system failure rate; for the power supply system the failure rate is 1/1008 hours.

The system reliability function is

$$R(t) = e^{-\lambda t}.$$

R(t) gives the probability of survival over the time period $t > 0$.

The ring magnet power supplies (RMPS) reliability for a one-week experiment would be 84.7%.

V. DEVELOPING AN RMPS SYSTEM

In developing a ring magnet power supply system the following nine steps should be incorporated.

1) Determine the power supply system requirements.

2) Develop the preliminary design.

3) Calculate the failure rate using the part count method for a baseline failure rate.

4) Calculate failure rate, using the part stress method, with the military handbook MIL-HDBK-217F. [2]

5) Test the preliminary design.

6) Develop a final design.

7) Procurement/production.

8) Test the final design/production units.

9) Design upgrades.

VI. FAILURE DATA

Once the accelerator starts operation, failure records need to be maintained. Below is an example of IPNS's availability table for the last six years.

Our designs will be based on MIL-HDBK-217F, which assumes a constant rate of failure over the useful life of components ranging from ICs to solder joints. This is represented by the bathtub curve shown in Fig. 1.[2]

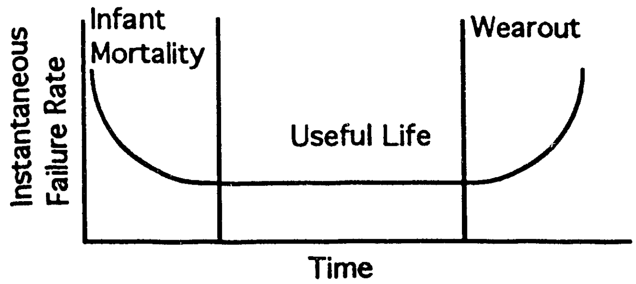

Fig. 1 Bathtub Curve

IPNS Availability Summary, FY 1988-FY 1993

Per 1000 Hours of Operation	FY'88 Failure Hours	FY'89 Failure Hours	FY'90 Failure Hours	FY'91 Failure Hours	FY'92 Failure Hours	FY'93 Failure Hours	Average Failure Hours	Power Supply Hours
H- Source	2.19	4.12	1.3	0.55	6.87	5.27	3.38	
Linac	4.58	6.91	4.42	1.27	2.84	7.5	4.59	
Stripper	0.23	0.36	0.28	0.14	0.13	5.27	1.07	
RF	4.98	1.5	8.85	8.84	6.67	18.15	8.17	
Bumper	1.66	6.32	0.79	0.07	0.35	0	1.53	1.53
RMPS	2.62	0.26	2.37	6.84	2.32	1.12	2.59	2.59
50 MeV	1.92	1.69	1.9	2.41	1.09	3.14	2.03	2.03
500 MeV	0.8	2.1	0.44	0.96	0.04	7.7	2.01	2.01
Magnets	0.43	1.14	1.17	0.41	0.39	3.35	1.15	
Vacuum	1.56	1.07	4.23	4.44	3.46	7.4	3.69	
Utilities	4.01	7.99	1.99	4.51	0.13	0	3.11	
Computer	17.28	1.36	3.25	0.76	1.97	1.12	4.29	
MCR Eqpt	0.07	0.88	4.42	1.41	0.48	0.71	1.33	
Septum	0.07	3.89	5.18	6.74	0.17	3.65	3.28	3.28
Kicker	11.28	8.61	4.74	5.74	8.18	7.2	7.63	7.63
Cool/Misc	0.4	0.17	0.85	3.47	4.81	2.13	1.97	
Total Failures Hours per 1000 Hours	54.08	48.37	46.18	48.56	39.9	73.71	51.80	19.06
Availability	95%	95%	95%	95%	96%	93%	95%	98%

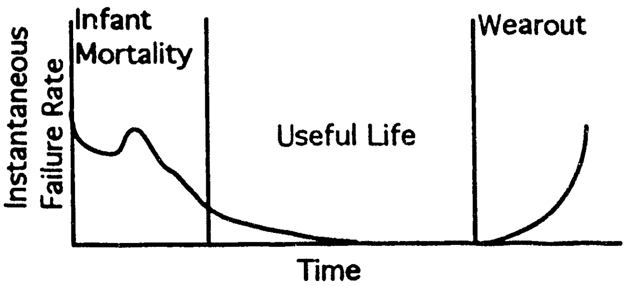

Fig. 2 Roller Coaster Curve

This curve assumes that between the initial period of infant mortality and a final wearout period, failures occur at a constant rate that can be minimized by choosing higher-quality components and reducing thermal and electrical stress. The predictions using the handbook should be thought of simply as tools for comparing design options. Possibly a better way to represent failure rates is the roller coaster curve, shown in Fig. 2. By keeping good records of failures, the job of designing a cost-effective maintance program will be greatly enhanced.

VII. CONCLUSIONS

It has been demonstrated that the approach and procedures outlined in this paper are key to achieving the proposed 99.9% availability goal of the IPNS 1 MW upgrade.

The results of the APS reliability workshop will be incorporated in the development of the magnet power supplies. As stated, the results are based on the experiences and operations of a number of facilities. Using this paper as a basis for the power supply design, it is anticipated that this goal is achievable within a scheduled time frame.

VIII. REFERENCES

[1] D.G. McGhee, "Study of 1 MW Neutron Source Synchrotron Dual Frequency Power Circuit for the Main Ring Magnets," these proceedings.

[2] Military Handbook (MIL-HDBK-217F), "Reliability Prediction of Electronic Equipment," Deparment of Defense, United States of America, 1990.

[3] IEEE Spectrum, "MIL Reliability: A New Approach," August 1992.

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