2.14 System availability

2.14.1 Introduction

Providing stable beams to scientists with a high level of availability is a primary design consideration for the ERL. Cornell's ERL team is involved in the operation of the CHESS light source with state of the art availability, and there has therefore been a commitment to this goal from the start. This began in the early design stages and will be maintained throughout the life of the experimental program.

Presented below is an outline of major components of the work to be done throughout the design and engineering phases. One has to anticipate that with new technologies it will take significant time to understand the main impediments to highly reliable operation. During the preparation for construction, this topic will be worked out in detail.

Establishment of reliability standards begins with a top-down analysis to define reliability goals for individual subsystems. Within each subsystem, reliability in terms of Mean Time Between Failure (MTBF) as well as maintainability in terms of Mean Time To Repair (MTTR), are considered from early concept through final design and implementation. Evaluation of component failure rates is done by using manufacturer data or by using well-established methods such as MIL-STD-756b or MIL-HDBK-217.

Availability may, of course, be increased by improving fault tolerance through redundant components or subsystems, by demanding conservatively rated power components, by specifying high reliability (such as rad-hard) components, and by testing extensively and by commissioning components. These all have costs that must be evaluated for efficacy [1].

During operation, aggressive maintenance programs, control of cooling water chemistry, electrical transient suppression, reduction of thermal cycling, and other preventative measures will increase MTBF.

In estimating facility availability, it will be assumed that the 'infant failures' stage is over and that any persistent failures related to design or manufacturing shortcomings have been corrected.

2.14.2 Availability accounting

The overall availability of beams for users is the product of the average availability of each of the systems that are critical for operation. A first approach to a full picture of the individual components would be to divide equally the allotment of non-available time among the systems. However, in this case some systems would find it impossible to meet their goals while others would do so easily. Thus an allotment reflecting practical realities is needed.

Availability is determined by two main components: 1) reliability, or mean time between failures (MTBF); and 2) time to fix and restore to service. This second component has three parts: 1) time to diagnose and localize the problem; 2) time to repair; and 3) time to restore the accelerator to service. For convenience these will all be grouped under the mean time to repair (MTTR). Availability is defined by:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}. \tag{2.14.1}$$

When a downtime in any subsystem will result in a down-time of the facility, then the facility availability will be the product of all of the subsystems availabilities. A reasonable allocation of subsystem availabilities may be determined by taking into account several features of each subsystem, including:

- Number of units
- Complexity of each unit
- Stressful conditions
- Self-diagnostic capabilities
- Time to replace/repair
- Redundancy

As detailed, reliability calculations provide better data, so the subsystem allocations can be adjusted appropriately. For example, a detailed analysis of expected availability of the International Linear Collider has been carried out using a MATLAB program [2].

Special considerations

Beyond the normal mechanical and electronic failures, several special conditions need to be considered in the ERL.

Momentary interruptions Cavity breakdown and similar transient phenomena can cause momentary loss of beam. While the mean time between such events will be significantly less than 'hard' failures, recovery will be generally fast and beam restored quickly (current ramp time). In addition, the effect of unexpected interruptions to data flow in experiments must be included in net availability calculations.

Ionizing and neutron radiation Over extended periods of time, radiation will degrade components. Most construction materials are reasonably rad-hard in the environment expected for an ERL. The exception is the permanent magnets in the insertion devices (ID), where a demagnetizing effect similar to heating close to the Curie temperature is seen. Here careful analysis of the radiation distribution, characterization of materials, and control of abnormal beam conditions must be carried out to extend the wiggler lifetime.

Electronics are particularly sensitive to radiation – both ionizing and neutron. To a greater extent than with the ID magnets, careful design, placement, and shielding must be done to assure satisfactory reliability. The primary source of lost electrons will be intrabeam scattering. With careful optics design, most of the scattered particles can be transported to localized collimators, minimizing the radiation along most of the beam path. Clearly the areas around these collimators must be avoided when placing electronics. In the ratchet wall areas, the electronics can be placed outside of the primary shielding wall. Assessment of beam losses, shielding, and sensitivity of electronic components (including integrated dose and single-event upset effects) will be given high priority as the ERL design evolves.

A third effect from radiation is that of personnel protection. In addition to carefully design shielding, at least two layers of active protection will be required to assure compliance with regulatory guidelines under any operating or fault conditions of the facility. This protection can be a reliability issue if not well designed and robust against false trips.

Fault tolerance

Fault tolerance can take several forms. Redundant components will reduce MTTR. Paralleled, hot-swappable components can reduce the loss of beam time by allowing continuous operation even with failure of an active component. Can the ERL run without a cryomodule with only minor retuning? What kind of failures can be tolerated until the next scheduled access?

Re-establishing operations

Once a failure preventing beam operation has occurred, a three-step recovery process begins:

1. Fault diagnosis – Where is the failure and what component must be replaced or repaired? Extensive monitoring and diagnostics, including 'intelligent' programs can reduce this component of the recovery
2. Replacement of the failed component(s) – Accessibility and swapability will be emphasized in the design stages to speed replacement of failed components. Lock-out systems will be designed to minimize overhead in access to power components.
3. Recovery of beam – Effects from temperature cycling and hysteresis will be minimized by designing bus work to allow access with the magnets energized. If a magnet shutdown is required, compensating methods will be employed to minimize the time needed for temperature stabilization after the repair. Computer control of the shutdown and startup processes will be used to save time and reduce human error.

2.14.3 Beam stability

Slow degradation in the performance of components – feedback systems timing, mechanical parts affecting vibration levels, tunnel motion – or the presence of electrical noise can affect beam stability and other conditions affecting availability of beams suitable for carrying out experiments. In addition to good design practices, appropriate instrumentation to detect and isolate sources of beam instability will be essential.

References

[1] Bellomo, P., A. Donaldson, and D. MacNair. *B-Factory Intermediate DC Magnet Power Systems Reliability Modeling and Results.* In *The 2001 Particle Accelerator Conference (PAC 2001)*, pages 3684–3686. Chicago, Illinois, USA (2001).

[2] Himel, T., *et al. Availability and Reliability Issues for ILC.* In *The twenty-second Particle Accelerator Conference, PAC'07*, pages 1966–1969. Albuquerque, New Mexico, USA (2007).