Early Operating and Reliability Experience with the CEBAF DC Magnet Power Supplies

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I. INTRODUCTION

The CEBAF accelerator is a five pass, recirculating, CW electron Linear accelerator [1]. There are a total of nine recirculation arcs connecting the two Linacs. Three experimental halls are serviced by the accelerator through separate transport channels. The magnet powering system for CEBAF consists of approximately 2000 independent control channels. About 1850 of these channels are low current, trim magnet power supplies. There are 28 higher power supplies used to energize the major bending elements. Over one hundred, 20 amp, active shunts are used to vary current in selected magnets in the major dipole strings. The majority of the magnetic elements are concentrated in the arcs and transport channels [2]. There are, however, a significant number of trim magnets in the source, injection transport and Linacs. Table 1 is a list of all magnets.

Element	Quantity
Major Dipoles	390
Correction Dipoles	1047
Quadrupoles	707
Sextupoles	96
Septa	27

Table 1 - Magnet Quantities

The correction dipoles, quadrupoles and sextupoles are each powered individually by a dedicated trim power supply channel. The arc and extraction channel dipoles are powered in series strings by the high powered supplies, known locally at CEBAF as "Box Power Supplies". Arc loads consist of some 30-40 magnets in series. Transport channel, path length control doglegs and septa box power supplies have loads ranging from 1 to 10 magnets. Shunts are installed on virtually all loads where two or more magnets are in series.

At this time, 95% of the power supplies are installed and commissioned. In the past twelve months, beginning in May of 1994, approximately 1200 trim magnet power supplies have been checked out. During this same period approximately 22 box power supplies and 100 shunts have been made operational. Full operation of the equipment has only been under way since early 1995. While this operation is only just beginning, much has been learned based on the reliability performance seen so far. The remainder of this paper describes the systems mentioned, their reliability problems, the fixes implemented to date, and some plans for the future.

II. SYSTEM DESCRIPTIONS

A. Box Power Supplies

The box power supplies were acquired from a commercial vendor via competitive bidding on a technical specification [3]. The supplies are Danfysik, System 8000 magnet power supplies. They contain some control and interface modifications for the CEBAF application. Table 2 is a list of the ratings of the supplies. The supply topology is a diode or SCR bridge followed by a series transistor regulator output. A precision DCCT and temperature stabilized DAC form the current regulation circuit that drives the transistor bank. Regulation is 10 PPM.

Power - kW	Voltage - V	Current - A	Quantity
14	50	270	11
42	65	645	2
66	300	220	5
152	660	230	7
161	250	645	3

Table 2 - Box Power Supply Parameters

B. Shunts

Shunts have been placed across selected magnets in each series string to provide a low cost, independent knob for steering corrections. The shunts are capable of bypassing up to 20 amps or 400 Watts, whichever is greater, around the selected magnet [4]. The shunts are implemented using MOSFET power transistors. The current regulation is 0.05%.

C. Trim Power Supplies

The trim powering system has been described previously [5]. Each rack contains up to 32 trim cards, two bulk voltage power supplies and a general purpose utility chassis. The trim cards are 200W, linear, bipolar current regulators capable of 10 amps output. The regulation is performed by a temperature controlled analog block containing a current measuring shunt, preamp, DAC and error amplifier. Regulation is 100 PPM. The utility chassis provides control power as well as rack control and interlock coordination.

D. Controls

Each box power supply, shunt and trim card has its own embedded microprocessor for communication, control and error status monitoring. Communication to the supplies is via an RS-485 serial link driven by a CAMAC based power supply Scanner Module. Virtually all high level accelerator controls are now implemented through EPICS, a VME based system that drives the CAMAC serial link. Alarm monitoring is performed by EPICS.

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E. Availability/Reliability Requirements

An availability budget for each accelerator subsystem has been set. The budgeted goals are gradually raised over a five year period beginning in 1994. These increasing availability numbers reflect the transition from a commissioning stage to full operation.

Availability is defined as the ratio of actual operating time to scheduled operating time. With overall accelerator availability set by design mandate, each subsystem is allocated a portion of the total budget. Availability is related to the Mean Down Time (MDT) and the Mean Time Between Failures (MTBF) by;

$$A = 1 - MDT/MTBF$$

The total availability of a group of subsystems is just the product of the individual availability numbers. The MTBF for a set of k independent systems is given by:

$$MTBF = 1/(N_1\times\lambda_1+N_2\times\lambda_2+...+N_k\times\lambda_k),$$

where N is the number of elements in the system with a failure rate of λ and $1/\lambda$ is just the per unit MTBF of the element. The availability requirement for the power supply systems is given in Table 3.

	FY94	FY95	FY96	FY97	FY98
Trims	0.92	0.95	0.97	0.98	0.98
Box PS & Shunts	0.95	0.97	0.985	0.99	0.99

Table 3 - PS Availability Budget

By making some assumptions about the MDT for the power supply system elements and using the availability requirements above, the required per unit MTBF for each element may be calculated. These values may then be compared with either vendor supplied data or with estimates for elements with similar complexity. This exercise will shed some light on where improvement efforts should be concentrated and will determine if the goals are achievable.

For the case of the box supplies and shunts in FY98, it is assumed that the availability budget is split equally between the two distinct elements; that is $A_1=A_2=0.995$. The MDT for the box power supply is estimated to be 4 hours since repairs generally take place in situ. The MDT for the shunts is estimated to be 1 hour since these cards can be swapped and repaired off line. Based on these assumptions, the required per unit MTBF for the box supplies and the shunts are 22,400 hours and 20,000 hours respectively. Both of these values seem achievable by the hardware as is the availability.

A similar analysis for the trim system is quite revealing. For FY98 the trim system availability budget is 0.98. In this case again, the assumption is made that the availability requirement is broken into two equal pieces shared by elements of the trim system. The first element is the 1850 trim cards. Using an availability of 0.99 and an MDT of 0.5 hours (hot swap capability in this case), a required per unit MTBF of 92,500 hours is calculated. The second element in the trim system is the approximately 120 bulk power supplies and 60 utility chassis. Using a 0.99 availability figure and a 1 hour MDT, a required per unit MTBF of 18,000 hours is calculated. While the bulk supply and utility chassis MTBF seems achievable, there clearly is a problem with the trim cards. What can be done?

A 40-50,000 hour MTBF might be achievable after some time and some expense with the trim cards. That means that the MDT needs to be decreased or the trim card availability allocation within the total power supply budget needs to be decreased in order to reach a total power system budget of 0.97 by FY98. It is believed that both these options are possible. The MDT should decrease as power supply personnel become more experienced. Also as operations personnel become more experienced in identifying and compensating for failed correctors, the beam downtime per failure should decrease. Improvements in the other elements of the power system will mean that more of the total availability allocation will be used by the trims. Whether a full factor of two will be achievable in these areas remains to be seen.

III. PROBLEMS AND CORRECTIONS

A. Box Power Supplies

There has been only one operational failure of the box power supply hardware to date. Other problems have occurred but these were related to either installation or load failures. Both ground faults and thermal problems have been observed. CEBAF has modified the ground fault detecting circuit in the power supplies due to deficiencies in its ability to detect all faults and latch them. With approximately 3.5 months of running (at 60% scheduled up time) and an excess of 20 supplies operating, one failure yields an observed MTBF of greater than 25,000 hours.

B. Shunts

Approximately six shunt cards have been changed in the same 3.5 months of service as described above. Of these, only one failure is believed to have been serious enough to have caused machine interruption. Based on six card replacements, the observed MTBF is approximately 25,000 hours.

C. Trim Power Supplies

As may be surmised from the approximate numbers given for the box supplies and shunts, complete failure tracking or downtime accounting systems have not been implemented yet. As in the previous cases, only general comments are possible at this time without a detailed tracking system.

There have been 22 bulk power supply failures in the past 15 months. The supplies are returned to the manufacturer under warranty for repairs. Failure reports indicate that two thirds of the problems were in the automatic voltage-current mode cross-over circuitry. Most failures seem to occur at start-up following extended machine maintenance periods. Based on an estimated 5000 hours of operating time for the 120 supplies, the calculated MTBF is in the 25-30,000 hour range.

Utility chassis failures have been greatly reduced during the last year due to several upgrades being made to all 60 units. Additional cooling was added to the chassis to reduce the ambient temperature seen by the control power supplies. The control power distribution connections for these supplies, internal to the chassis, were re-worked after it was noted that bad connections were responsible for intermittent and/or low output voltages. The 2-3 failures seen during the 3.5 months of operation since the upgrades has resulted in an MTBF in excess of 30,000 hours.

Prior to last summer, trim cards were failing at a rate of slightly more than one per day. Since commissioning and installation was still in progress, the exact number of cards in service at any particular time has been difficult to reconstruct. It is probably safe to say that the MTBF at that time was less than 20,000 hours. The causes for removal were varied, however, one common problem was seen in many of the failures. A surface mount chip capacitor on the temperature controlled analog block, used for input power filtering, was frequently burned up. After testing, it was determined that the capacitor could be removed without adversely affecting the circuit performance. All cards in service have had this modification. The failure rate has been reduced to approximately one every 3-5 days. The MTBF is believed to be in the 50-100,000 hour range. Confirmation of this awaits better failure tracking.

D. Controls

The only responsibility for external hardware controls retained by the power supply group is for the CAMAC based Scanner Modules. Failure statistics for this item are not well documented, however, some observations are possible. The card, developed by a commercial vendor for CEBAF, experienced mostly soft failures. That is, there were no bad components but status information was corrupted. These problems were traced to noise within the crates and on the card itself. Additional power bypassing on the crate controller along with correction of the mechanical alignment of edge connectors improved the situation. Finally, changes to the on board EPLD logic along with the replacement of FCT TTL devices with LS TTL devices cured the problem. All three of these items contributed to excessive noise levels on the card's data and control lines. Since the repairs the cards have performed reliably. There are in excess of 100 scanner cards in service.

IV. PLANS FOR THE FUTURE

A. Failure Tracking

The two failure tracking utilities used to date, one accelerator wide, one power group internal, have not proved effective. Both suffer from reporting inconsistencies and a lack of useful information retrieval features. Also there is no good accelerator downtime recording system in use. Subsystem availability is consequently not well measured. To improve the failure tracking, the RF and Power Supply Groups are collaborating on the set up of new database for this purpose. The database chosen is Access running under Windows for WorkGroups [6].

B. Upgrades

Planned software upgrades include improvements to the EPICS control screens to allow more in depth remote diagnostics and better Alarm Monitoring. The improvements should reduce the MDT by speeding problem identification.

Additional monitor points are planned for the box supplies to allow safer and speedier diagnostic work. More detailed reporting of interlock status is planned to help remove some status ambiguity. A proposal is on the board for removing completely the CAMAC based scanner by installing its functionality in the EPICS VME crate. The CAMAC hardware is a leftover from TACL, the original CEBAF control system.

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