SLAC ACCELERATOR OPERATIONS REPORT: 1992-1995*

R. Erickson, C.W. Allen, T.K. Inman, W. Linebarger, M. Stanek, Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309 USA

Operational statistics for the linear accelerator programs at SLAC are presented, including run-time records for the SLC, FFTB, and fixed target programs. Also included are summaries of reliability and maintenance-related statistics and a discussion of the analysis tools used to study error messages generated by the control system.

I. PROGRAM CHRONOLOGY

The SLAC linear accelerator programs are summarized in Table 1 for the period of January 1992 through March 1995. SLC machine development is defined to include extended periods of pre-run system turn-on, new system commissioning, and experiments to characterize and improve the performance of various accelerator systems. SLD logging refers to periods of SLC operation dedicated to producing Z particles in the SLD detector, with the detector on and recording data. Fixed target runs to ESA are periods when polarized electrons were delivered to fixed-target experiments in the End Station A experimental hall. Scheduled off times in this table are relatively long periods typically needed for major installations and upgrades. Time periods when the accelerator was off for holidays are not listed. The FFTB runs are periods of low intensity, low repetition rate (typically 30 Hz) operation in which damped electrons were delivered to the Final Focus Test Beam facility. The FFTB is a beam transport system that extends through the beam switchyard and is used for focusing the electron beam to sub-micron sizes for the study of future linear collider technology and for esoteric physics experiments requiring extraordinarily high charge density.

II. TIME ACCOUNTING

Time accounting records are kept by the accelerator systems operators, who record the number of hours devoted to each of the categories in the first column of Table 2 at the end of each eight hour shift. The experimental runs summarized in this table include only the time periods dedicated to logging data in the indicated detector and exclude extended pre-run turn on and commissioning time. The run periods begin when the accelerator and the detector are ready to begin production data collection and continue until the detector is scheduled to shut down.

Time period	Program
2 Jan 92 - 1 May 92	SLC machine development.
1 May 92 - 18 Aug 92	SLD logging - First polarized electrons in SLC.
18 Aug 92 - 3 Oct 92	SLC machine development.
4 Oct 92 - 7 Nov 92	Scheduled off - prepare for fixed target program.
8 Nov 92 - 23 Dec 92	Fixed target ESA run - E142.
2 Jan 93 - 26 Feb 93	SLC machine development.
26 Feb 93 -14 Aug 93	SLD logging.
15 Aug 93 - 1 Sep 93	SLC machine development.
1 Sep 93 - 1 Nov 93	Scheduled off - prepare for fixed target program. Damping ring vacuum chamber upgrade. SLC final focus upgrade.
1 Nov 93 - 23 Dec 93	Fixed target ESA run - E143.
4 Jan 94 - 6 Feb 94	Fixed target ESA run - E143.
7 Feb 94 - 19 Jun 94	SLC machine development - commission new damping rings and final foci. ~15 days of FFTB (Apr, May).
20 Jun 94 - 31 Aug 94	SLD logging.
1 Sep 94 - 19 Sep 94	FFTB run.
20 Sep 94 - 3 Oct 94	SLC machine development.
3 Oct 94 - 23 Dec 94	SLD logging.
3 Jan 95 - 6 Jan 95	FFTB run.
6 Jan 95 - 3 Mar 95	SLD logging.
3 Mar 95 - 18 Mar 95	SLC machine development.
18 Mar 95 -31 Mar 95	FFTB run.

Table 1. SLAC program chronology 1992-1995.

The "experiment logging" category is defined as the time that a suitable beam (or colliding beams) was available to the scheduled experiment, and the detector

* *Work supported by Department of Energy contract DE-AC03-76SF00515.*

equipment was active and recording data. Machine development in Table 2 includes only brief (<1 day) interruptions to data logging, usually dedicated to measuring accelerator system parameters and implementing improvements. The extended periods of scheduled machine development work listed in Table 1 are not included here. Alternate programs are brief tests or experiments scheduled on short notice when the primary program can not be carried out as planned. This typically happens when some accelerator subsystem critical to the primary program is undergoing repairs while other accelerator systems, such as the injector system and the electron damping systems, are operating normally. Tuning is defined as any time when no specific hardware or software systems are known to be malfunctioning, yet the beam properties do not meet the requirements of the scheduled program. Typically this is the time spent by operators and accelerator physicists measuring and correcting beam parameters. Unscheduled down time is logged when a system or component has failed, rendering the beam unusable for either the main experiment or an alternate program. Scheduled off represents brief (<1 day) planned interruptions to the primary experimental program, typically for maintenance and minor upgrades or adjustments to existing systems. The extended scheduled off periods shown in Table 1 are not included here, nor are holiday periods.

	SLD 92	***SLD 93***	***SLD 94/5***	***ESA 92***	***ESA 93/4***	***FFTB 94/5***
Exp't Logging	*51%*	*63%*	*56%*	*66%*	*69%*	*69%*
Machine Develop.	*9%*	*6%*	*4%*	*1%*	*0%*	*7%*
Alternate Program	*1%*	*1%*	*4%*	*0%*	*4%*	*1%*
Tuning	*19%*	*11%*	*10%*	*16%*	*12%*	*8%*
Unsched. Down	*18%*	*17%*	*23%*	*13%*	*8%*	*11%*
Sched. Off	*2%*	*2%*	*3%*	*4%*	*7%*	*4%*
Total Hours	*2616*	*4079*	*5065*	*1088*	*1439*	*1560*
Total Z (x 1000)	*10*	*55.7*	*100*	–	–	–
Ave. Lum (Z/hr)	*7.5*	*21.7*	*35.3*	–	–	–
Approx. Polarization	*21%*	*65%*	*79%*	*40%*	*85%*	–

Table 2. SLAC primary linac program run time accounting 1992-1995.

The percentage of time spent tuning decreased steadily during the period of this study for both SLC and fixed target programs, as diagnostic instruments were improved and new feedback systems were commissioned. This improvement occurred despite progressively more demanding requirements on beam quality. The decrease in experiment logging efficiency in 1994/95 compared to 1993 and the corresponding increase in unscheduled downtime were due mainly to the long repair and recovery times associated with five independent vacuum failures in the electron damping ring and the loss of two damping ring klystrons.

The bottom part of Table 2 summarizes the total hours corresponding to each experimental run, along with the approximate number of Z particles detected, the average luminosity, and the approximate beam polarization where applicable.

III. RELIABILITY AND MAINTENANCE STATISTICS

Hardware availability, defined here in terms of time when the accelerator hardware is not broken, is a measure of the overall reliability of the accelerator systems needed to carry out the accelerator program. The hardware availability, mean time to failure, and mean time to repair are listed in Table 3 for each of the major accelerator programs in the last three years. These quantities are defined as follows:

Availability = 1- (Downtime / Scheduled Operating Hours).
Mean Time To Failure (MTTF) = Sched hrs / # of Failures.
Mean Time To Repair (MTTR) = Downtime / # of Failures.

Hardware failures as defined in this section are those failures that noticeably interrupt or impede a scheduled running program and do not require testing or inspections to locate. As these data indicate, the hardware availability is consistently better during ESA and FFTB operation than during SLC operation. This is mainly because the ESA and FFTB programs require only electrons (no positrons) and thus require fewer active devices. These programs are also more tolerant of imperfect beams than is the SLC program.

	Availability	MTTF	MTTR
SLC 1992	81.8 %	8.3	1.5
SLC 1993	82.8 %	7.7	1.3
SLC 1994	80.7 %	8.5	1.6
ESA 1992	87.0 %	12.4	1.6
ESA 1993/4	93.3 %	12.7	0.9
FFTB 1994	90.3 %	12.4	1.2

Table 3. SLAC hardware reliability summary.

IV. CONTROL SYSTEM MESSAGE ANALYSIS

The SLAC accelerator complex consists of thousands of active devices, such as power supplies and mechanical transducers of various kinds, each of which must operate within prescribed tolerances in order to achieve the desired beam characteristics. The acceptable tolerances for many of these devices are stringent compared to the standards normally achieved in large scale industrial applications of commercially available equipment. As a result, parameter variations induced by mechanical vibrations, deviations in ambient temperature or electrical supply voltage, or other effects, occur frequently and often have detrimental effects on the quality of the beams. Constant monitoring and analyses of these effects are essential to identifying and rectifying problems of this kind.

Accelerator systems that drift in and out of prescribed tolerances typically do not interrupt machine operations, but may severely degrade the quality of the beams. Because of the adverse impact on overall efficiency of these kind of problems, a set of software tools and analysis procedures have been developed to address these issues.

The linac and beam delivery systems are monitored and controlled through a VAX-based computer control system. The control system includes a feature called the Summary Information Process (SIP), which checks a selected list of measured device parameters against prescribed database tolerances approximately every 15 seconds. Currently 4894 devices are monitored by this process whenever the SLC is operating. Whenever the status of any of these devices changes to an out-of-tolerance condition, a warning "error message" is generated by SIP. These error messages are presented to the control room operators on scrolling displays and are automatically recorded for later analyses.

By ranking the frequency of messages for each individual device, recurring problems can be identified. Devices with frequent intermittent failures and devices operating too close to their tolerance are easily identified by the large number of messages they generate. Daily and monthly reports are produced that list the highest counting devices in descending order. The data are sorted by major accelerator systems (injector, damping rings, etc.) and by type of device (analog and digital signals, temperatures, magnets and power supplies, stepping motor devices, damping ring RF devices, vacuum devices, etc.). These summaries do not include linac RF systems, which are processed and analyzed separately. The reports are distributed to designated managers responsible for each of the major subsystems.

Table 4 lists the monthly SIP error counts during SLC operations in recent years. The error frequency starts out high at the beginning of each running period as old equipment is reactivated and new or upgraded equipment is commissioned. The monthly count then decreases progressively over the duration of each period of continuous operation as the machine stabilizes and problems are identified and repaired.

	1992	1993	1994	1995
Jan				36
Feb	80	58		21
Mar	46	47		
Apr	69	42		
May	79	43		
Jun	40	40		
Jul	43	37	38	
Aug	43	44	33	
Sep			31	
Oct			30	
Nov			26	
Dec			19	
Avg	57	44	30	28

Table 4. SIP error counts (x 1000) for 1992-1995.

A subset of the SIP error data for the period of November 1994 through January 1995 is presented in Table 5. The 50 worst devices (the specific devices that generated the largest numbers of SIP errors) are grouped by type of device and the corresponding percentages of all the SIP errors for the time period are shown. These 50 devices accumulated 32577 SIP errors or 40.3% of all SIP errors during this time period.

13 Feedback loop devices	10.1 %
10 Stepper motor devices	8.9 %
4 Analog sensors (temps, vacuum, etc.)	4.3 %
2 Damping Ring RF devices	3.5 %

4 Large DC power supplies	3.5 %
5 Vert. steering corrector magnets	3.3 %
3 Gun laser system	1.7 %
3 Horiz. steering corrector magnets	1.5 %
2 Quadrupole trim power supplies	1.4 %
3 Quadrupole power supplies	0.9 %
1 Kicker magnet	0.9 %

Table 5. Summary of the fifty devices that generated the most SIP errors as explained in the text.