Availability and Reliability Issues for the XFEL

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Contents

Introduction and purpose of studies * The availability simulation **Wake up ILC people** What was modeled (important) assumptions) ***** Some results Conclusions

Introduction

- * Availsim is a Monte Carlo simulation developed over several years for linear collider studies.
- Given a component list and MTBFs and MTTRs and degradations it simulates the running and repairing of an accelerator.
- It can be used as a tool to compare designs and set requirements on redundancies and MTBFs.
- * It has now been applied to the XFEL.

Why a simulation?

- We chose to go with a simulation instead of a spreadsheet calculation for the following reasons:
 - Including tuning and recovery times in a spreadsheet calculation is difficult.
 - Fixing many things at once (during an access) is also difficult to put in a simple spreadsheet formula.
 - If later, one wants to more carefully model luminosity degradation on recovery from downtimes a simulation is simpler
 - A disadvantage of a simulation is its use of random numbers so one needs high enough statistics to get a meaningful answer. This is particularly a concern if one wants to compare two slightly different cases.
 - Random number seeds are handled in a way to allow meaningful comparisons of similar cases.
 - A 20 year simulation which gives good enough statistics takes 90 seconds on my laptop

The Simulation includes:

- 1. Effects of redundancy such as 21 DR kickers where only 20 are needed or the large energy overhead in the main linac
- 2. Some repairs require accelerator tunnel access, others can't be made without killing the beam and others can be done hot.
- 3. Time for radiation to cool down before accessing the tunnel
- 4. Time to lock up the tunnel and turn on and standardize power supplies
- 5. Recovery time after a down time is proportional to the length of time a part of the accelerator has had no beam. Recovery starts at the injectors and proceeds downstream.
- 6. Manpower to make repairs can be limited.

The Simulation includes:

- 7. Opportunistic Machine Development (MD) is done when part of the accelerator is down but beam is available elsewhere for more than 2 hours.
- 8. MD is scheduled to reach a goal of 1 2% in each region of the accelerator.
- 9. All regions are modeled in detail down to the level of magnets, power supplies, power supply controllers, vacuum valves, BPMs ...
- 10. The cryoplants and AC power distribution are not modelled in detail.
- 11. Non-hot maintenance is only done when the accelerator is broken. Extra non-essential repairs are done at that time though. Repairs that give the most bang for the buck are done first.

The Simulation includes:

12. PPS zones are handled properly e.g. can access linac when beam is in the injector. It assumes there is a tuneup dump at the end of each region.

13. Kludge repairs can be done to ameliorate a problem that otherwise would take too long to repair. Examples: Tune around a bad quad in the cold linac or disconnect the input to a cold power coupler that is breaking down.

14. During the long (1 month) shutdown, all devices with long MTTR's get repaired.



ILC – XFEL – SyncLight differences

	ILC	XFEL	SyncLight
Expt. Duration	years	week	shift
Care about	int lum	unsched downs	unsched downs
Allowed unsched downtime (%)	25	10 (e- only)	5
Budgeted unsched downtime (%)	15	7 (e- only)	
Downtime held as Contingency %	10	3	
Scheduled maintenance days	none	2 wks 8+4	
Run length (months)	9	11	
Num. of components (thousands)	250	17	
Cost (accel+expts) (\$B)	7.6	1.4	Sum The
cool down time (minutes)	60	15	
access recovery time (minutes)	60	30	1 1 4 1

Scheduled Maintenance Days New feature added for XFEL

- Regular shutdown for repairs/maintenance
- Counts as scheduled downtime, not unscheduled. Better for short term users.
- All repairs which can be completed with available manpower in available time are done. Most bang for buck first.
- Maintenance items (e.g. cleaning filters) which don't break things are not simulated.
- If recovery is longer than scheduled, extra is unscheduled down.
- If recovery is > 2 hours early, opportunistic MD is done.
- If we were down at beginning of maintenance day, remaining down is changed to scheduled.

Mined data from old accelerators

Component	MTBF (hr)	MTTR (hr)	comment
Water cooled magnet	1,000,000	8	Average from SLC. There have been magnet families with
			MTBF > 13,000,000
Air cooled magnets	10,000,000	2	SLC
Super conducting magnet	10,000,000	472	MTBF given is 10 times that of Tevatron dipole magnet as
			the SC quads in ILC are much lower current. We assumed
			a failed SC quad would be tuned around in 2 hrs as a
			kludge repair
Kicker pulsar	10,000	2	SLC
Magnet Power supplies	50,000	2 or 4	SLAC and FNAL average. The larger MTTR is for large
			not easily replaceable supplies
Electronics modules	100,000	1	This is a crude average over many types of electronics
			modules
Water flow switch	250,000	1	SLAC
Movable collimators and	100,000	8	SLAC
stoppers and valves			
DR klystron	30,000	8	SLAC
Linac Modulator	50,000	4	SLAC

MTBF data for accelerator components is scarce and varies widely



List of sub-decks

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	A Really						RF gun components including
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	Part Carl						non SCRF components of e-
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				State of the			SCRF components of e- injector
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	compress	or 1					L1+B1+B1D
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cryomodule	yes	compressor 1	linac	370	32	0	RF for L1 in front of compressor 1
	compress	or 2					L2+B2+B2D
compressor 2	yes	compressor 2	A RESSER	(partited)		Ter al a la	non RF compressor 2 hardware
cryomodule	yes	compressor 2	linac	1,500	96	0	RF for L1 in front of compressor 1
	main linac	:					L3
main linac	yes	main linac	10000000	DE CONSER	ELSNEL S	States -	main linac
cryomodule	yes	main linac	South States	18,000	800	0	RF for main e- linac
	collimation	า					CL+TL+TLD+T1
collimation	yes	main linac	HOUSE STA	Cult Shout	Callanas	10000	Collimation, transport, dump
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	SASE 1						T4 + SA3 + T4D
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system	componen	subsys/se	problem na	quantity	parameter	add/mult	degradatio	MTBF	MTTR S	till broker	access ne	n repair pe randseed	Starting M
			laser + pol	arized gun	+ buncher	+ LTR							
			e- source r	non-RF incl	uding laser	, polarized	gun, bunch	er and linac	to ring trans	port line.	Goes to 80) MeV point.	
	e- source	laser	e- source l	aser and la	ser optics (elements							
Diagnostic	laser	beamline	broken	1	luminosity	mult	0	2.00E+04	2		-1	2	2.00E+04
PS + contr	Laser PS	beamline	broken	2	luminosity	mult	0	1.00E+06	2		-1	2	1.00E+06
Vacuum	Vac Mech	beamline	broken	2	luminosity	mult	0	5.00E+05	8		1	2	5.00E+05
Vacuum	VacP	beamline	broken	5	luminosity	mult	0	1.00E+07	4		1	2	1.00E+07
Vacuum	VacP pow	beamline	broken	5	luminosity	mult	0	1.00E+05	1		-1	1	1.00E+05
Vacuum	VacV	beamline	broken	2	luminosity	mult	0	1.00E+06	4		1	2	1.00E+06
Vacuum	Vac∀ cont	beamline	broken	2	luminosity	mult	0	1.90E+05	2		0	1	1.90E+05
controls	timing	beamline	broken	1	luminosity	mult	0	3.00E+05	1		0	1	3.00E+05
controls	other contr	beamline	broken	1	luminosity	mult	0	3.00E+05	1		-1	1	3.00E+05
Water sys	Water pun	beamline	broken	2	luminosity	mult	0	1.20E+05	4		-1	2	1.20E+05
Water sys	Water inst	beamline	broken	6	luminosity	mult	0	3.00E+05	2		-1	2	3.00E+05
Water sys	Flow Swite	beamline	broken	6	luminosity	mult	0	2.50E+06	1		-1	1	2.50E+06
AC power	Electrical -	beamline	broken	0	luminosity	mult	0	3.60E+05	4		0	2	3.60E+05
AC power	Electrical -	beamline	broken	5	luminosity	mult	0	3.60E+05	2		0	2	3.60E+05
	e- source	pol gun	e- source (components	s that work	on the elec	tron beam:						
Magnets	Corrs - car	beamline	broken	4	luminosity	mult	0	1.00E+07	2		1	2	1.00E+07
PS + contr	HVPS	beamline	broken	1	luminosity	mult	0	1.00E+06	2		1	2	1.00E+06
PS + contr	HVPS con	beamline	broken	1	luminosity	mult	0	1.00E+06	1		-1	1	1.00E+06
PS + contr	PS Corrs o	beamline	broken	4	luminosity	mult	0	4.00E+05	2		-1	1	4.00E+05
PS + contr	PS control	beamline	broken	4	luminosity	mult	0	1.00E+06	1		-1	1	1.00E+06
Vacuum	Vac Mech	beamline	broken	1	luminosity	mult	0	5.00E+05	8		1	2	5.00E+05
Vacuum	VacP	beamline	broken	5	luminosity	mult	1	1.00E+07	4		1	2	1.00E+07
Vacuum	VacP pow	beamline	broken	5	luminosity	mult	1	1.00E+05	1		-1	1	1.00E+05
Vacuum	VacV	beamline	broken	2	luminosity	mult	0	1.00E+06	4		1	2	1.00E+06
Vacuum	VacV cont	beamline	broken	2	luminosity	mult	0	1.90E+05	2		0	1	1.90E+05
Diagnostic	BPMs	diagnostic	broken	4	luminosity	mult	0.999	3.00E+05	1		-1	1	3.00E+05
controls	controls ba	sector	broken	1	luminosity	mult	0	3.00E+05	1		0	1	3.00E+05
controls	local back	sector	broken	10	luminosity	mult	0	3.00E+05	1		0	1	3.00E+05
controls	Controls P	region	broken	2	luminosity	mult	0	3.00E+05	1		0	1	3.00E+05
controls	MPS & Fa	region	broken	1	luminosity	mult	0	5.00E+03	1		0	1	5.00E+03
AC power	Electrical>	Utility pow	broken	1	luminosity	mult	0	3.60E+05	4		0	2	3.60E+05
AC power	Electrical -	Utility pow	broken	10	luminosity	mult	0	3.60E+05	2		0	2	3.60E+05
	e- source	buncher			,								
Magnets	Bends	beamline	broken	0	luminosity	mult	0	2.00E+07	8		1	2	2.00E+07
Magnets	Quads	beamline	broken	10	luminositv	mult	0	2.00E+07	8		1	2	2.00E+07
Magnets	Corrs - car	beamline	broken	20	luminositv	mult	0	1.00E+07	2		1	2	1.00E+07
Magnets	Solenoids	beamline	broken	10	luminositv	mult	0	2.00E+07	8		1	2	2.00E+07
Magnets	Wigglers	beamline	broken	 N	luminositv	mult	n n	1.00E+07	- 8		1	2	1.00E+07
				-							-		

Starting Modeling Assumptions (XFEL/ILC)

- * The full complement of 117 cryomodules is installed.
- (Only 3 upstream /all) klystrons+modulators are accessible.
- * Accelerator can run with any other klystron off.
- * (Few/Most) electronics modules can be hot swapped.
- Tune up dump and shielding between each part of accelerator
- # Global controls causes (0.2/0.2)% downtime
- # Global water system causes (0.2/0.0)% downtime
- Some cryoplant is down 1% including outages due to their incoming utilities. There is (1/6) cryoplant.
- Major power circuits cause (0.5/0.5)% downtime

Starting Modeling Assumptions (XFEL/ILC)

- Power coupler interlock electronics and sensors (do not have / have) MTBF of 1E6 due to redundancy.
- Cavity tuner motors have MTBF of 1E6, 2 times better than SLAC warm experience and MUCH better than TTF experience.
- Failed linac quads can be tuned around in 2 hours
- Most failed correctors can be tuned around in 0.5 hours
- LLRF, klystron support electronics, SC quad supplies (are/are not) in accel tunnel. Other power supplies are accessible
- Hot spare klystron/modulator with waveguide switches in (no/low energy) linac regions
- Magnet power supply MTBF of (50,000 for most magnets and 100,000 for SC magnets whose supplies are in the tunnel/200,000). ILC assumed redundant regulators.
- It takes (6/8) hours to replace a klystron

Initial downtime causes

Sum of % down * 100	And And And
comp name	Total
cryo plant beamline	127.3
Kicker pulser beamline	104.9
coupler interlock electronics coupler	100.6
coupler interlock sensors coupler	99.8
Power supplies strings beamline	97.1
Power supplies SC quad beamline	65.5
site power beamline	65.2
Quads beamline	49.9
Flow Switch - quads beamline	44.0
Electrical05<<0.5 Utility power	35.1
Vac Mech device beamline	34.7
PS controller - corr can tune around beamline	34.5
PS controller SC quad beamline	27.8
Central Water beamline	25.2
Kickers beamline	24.8
local backbone sector	24.7
Controls sitewide beamline	23.1
PS controller string beamline	23.1
schedMaintn	17.9
Klystrons klystron	17.4

24 electronic cards + 6*24 sensors per RF unit – any failure trips it off

Lumped systems

Total XFEL downtime = 11.6% where budget = 7%

Total ILC downtime = 31% where budget = 15%, but ILC started with some components assumed better than now

Needed XFEL MTBF Improvements

	Downtime		
Needed	(%) due to	Nominal	Nominal
Improvement	these	MTBF	MTTR
factor	devices	(hours)	(hours)
10	0.1	100,000	1
10	0.1	600,000	1
5	0.2	50,000	2
2	0.3	100,000	1
12->13	0.2	7,000	2
3	0.2	250,000	1
	0.3	100,000	1
	1.4		
	0.7		
	0.2		
	0.2		
	0.2		
RESERVENCES IN	0.2	40,000	6
	0.2	5,000	1
	Needed Improvement factor 10 10 5 2 12->13 3	Needed Downtime Needed (%) due to Improvement these factor devices 10 0.1 10 0.1 10 0.1 10 0.1 10 0.1 10 0.1 10 0.1 11 0.1 12->13 0.2 3 0.2 3 0.2 14 0.3 0.2 0.3 12->13 0.2 3 0.2 0.3 0.2 1.4 0.3 0.2 0.3 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2	Needed Oowntime Needed (%) due to Nominal Improvement these MTBF factor devices (hours) 10 0.1 100,000 10 0.1 600,000 5 0.2 50,000 2 0.3 100,000 12->13 0.2 7,000 3 0.2 250,000 10 0.3 100,000 12->13 0.2 250,000 3 0.2 250,000 10 0.3 100,000 10 0.3 100,000 10 0.2 250,000 10 0.2 250,000 10 0.2 250,000 10 0.2 40,000 10 0.2 40,000 10 0.2 5,000

Comments on MTBF improvements

- * There are 6 coupler sensors and interlock electronics channels per coupler with no redundancy. Not surprising it is a problem. However, not problem at FLASH, so maybe MTBF of 100k hours per 6 channel electronics card is too short? Can one require 2 problems before tripping (ILC assumes this)?
- Kicker problem easily fixed with extra kicker and pulser. Was already OK for 17.5 GeV energy
- Power supplies are single points of failure, commonly a problem in accelerators.
 - APS gets MTBF of 560,000 hrs, 10 times greater than SLAC/FNAL/DESY.
 - They stress the supplies before each run and monitor internal temperatures and voltages so degrading components can be replaced on scheduled maintenance days.

Needed ILC MTBF Improvements

		Downtime		
	Needed	(%) due to	Nominal	Nominal
	Improvement	these	MTBF	MTTR
Device	factor	devices	(hours)	(hours)
power supplies	20	0.2	50,000	2
power supply controllers	10	0.6	100,000	1
flow switches	10	0.5	250,000	1
water instrumention near pump	10	0.2	30,000	2
magnets - water cooled	6	0.4	3,000,000	8
kicker pulser	5	0.3	100,000	2
coupler interlock sensors	5	0.2	1,000,000	1
collimators and beam stoppers	5	0.3	100,000	8
all electronics modules	3	1.0	100,000	1
AC breakers < 500 kW		0.8	360,000	2
vacuum valve controllers		1.1	190,000	2
regional MPS system		1.1	5,000	1
power supply - corrector		0.9	400,000	1
vacuum valves		0.8	1,000,000	4
water pumps		0.4	120,000	4
modulator		0.4	50,000	4
klystron - linac		0.8	40,000	8
coupler interlock electronics		0.4	1,000,000	1
vacuum pumps		0.9	10,000,000	4
controls backbone		0.8	300,000	Tom Himel

XFEL Simulation Results

Simulated Simulated

		Simulateu	Simulateu	
		%	% time	Simulated
	ATTENDED IN A STATE OF THE STATE OF	unsched	fully up	%
		time down	taking	scheduled
Run		incl forced	data or	maintenan
Number	XFEL description	MD	sched MD	се
	TDR 20 GeV 8 + 4 sched down			the second
XFEL1	every 2 weeks	11.6	84.8	3.5
XFEL2	XFEL1 but 17.5 GeV	10.0	86.4	3.5
XFEL3	XFEL1 but MTBF table A	7.0	89.4	3.5
XFEL4	XFEL3 but no sched down	7.3	92.7	0.0
	XFEL3 but sched down every 4		and a second	
XFEL5	weeks	7.1	91.1	1.8
XFEL6	XFEL3 but 8 + 8 hour sched down	6.6	88.6	4.7

For ILC availSim used as input for many design decisions

- Putting both DR in a single tunnel only decreased int lum by 1%. -- OK
- Is a hot spare e+ target line needed? -- Not if e+ target can be replaced in the specified 8 hours
- Confirm that 3% energy overhead is adequate in the linac.
- Showed that hot spare klystrons and modulators are needed where a single failure would prevent running.
- * Showed 7% availability loss for single tunnel.

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For XFEL points out potential problems I've chosen particular items to improve. Project needs to look for optimum (cheapest, lowest risk) solution Could the cryoplant or site power be made more reliable than assumed? Can coupler interlocks require 2 problems before tripping?

Benchmarking the Simulation

- A limited benchmark was done with HERA data. Using MTBFs and component counts taken from HERA as input, it correctly calculated the number of failures.
- Fancier features like repair time scheduling and recovery time have not been benchmarked.
 - Getting together list of components is real work.
 - MTBFs and MTTRs should be taken from accelerator under study. 50% errors easily happen. Real work.
 - Recovery time is usually accounted as "tuning" instead of downtime.
 - Often repairs are accounted as "scheduled downtime"
- Simulation results seem reasonable. Back-of-the-envelope checks are OK.
- Most important results are comparisons of two slightly different accelerators. Systematic errors cancel.

Conclusions

- Component availability for ILC is a major challenge. Must do R&D, plan, and budget for it up-front.
- * For XFEL, it is not past state-of-the-art, but more attention must be paid to it than for a typical HEP accelerator.
- X-ray beam-lines have not been modeled. They have few parts but with unknown reliabilities.
- * This simulation is a useful design tool for the ILC and XFEL and other accelerators. Code is available.