OPERATION OF THE FLASH LINAC WITH LONG BUNCH TRAINS AND HIGH AVERAGE CURRENT

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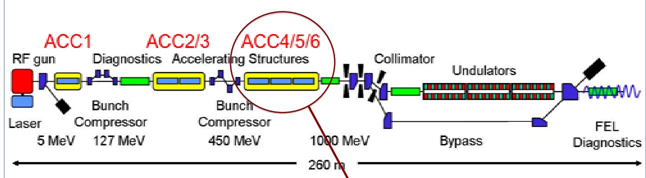
Abstract

XFEL and ILC both intend to accelerate long beam pulses of a few thousand bunches and high average current. It is expected that the superconducting accelerating cavities will eventually be operated close to their respective gradient limits as they are pushed to higher-energies. An international collaboration led by DESY has begun a program of study to demonstrate such ILC-like conditions at FLASH which serves as a prototype for both XFEL and ILC. To date there have been three short study periods.

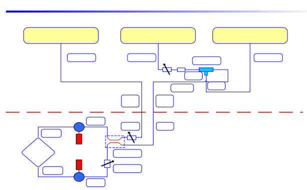
FLASH Accelerator



Comparison of machine parameters

		XFEL	ILC	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9

ACC456 is the focus of RF studies



Primary objectives of the "9mA" study

- Long-pulse high beam loading (9mA) demonstration
  - 800µs pulse with 2400 bunches (3MHz), 3nC per bunch
  - Cavity gradients approaching quench limits
  - Beam energy 700 MeV
  - ±0.1% energy stability over extended periods

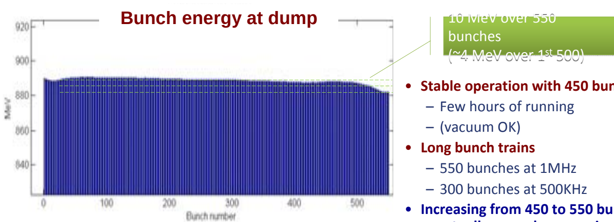
Primarily an LLRF study

- Characterize operational limits
  - Characterisation of energy stability limitations
  - Reliable operation close to quench
  - Klystron overhead needed for LLRF control
  - HOM absorber studies (cryo-load)
- Operations close to limits, eg
  - Robust automation of tuning and of routine tasks
  - Quench detection/recovery, exception handling
  - Beam-based adjustments/optimization

Operational challenge for FLASH
Well beyond typical beam parameters for photon users

High beam-loading long pulse operation

(550 bunches at 1MHz, ~2.5nC / bunch at dump, 890MeV)



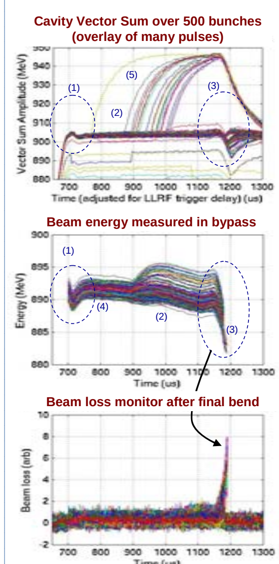
Result from September 2008

- **Stable operation with 450 bunches**
  - Few hours of running
  - (vacuum OK)
- **Long bunch trains**
  - 550 bunches at 1MHz
  - 300 bunches at 500KHz
- **Increasing from 450 to 550 bunches eventually caused vacuum incident**

Biggest issue to date: controlling beam loss in dump line

- High beam power (~6kW)
- Optics model and measurements do not agree well
- Narrow energy aperture, sensitive to LLRF tuning (see below)
- Diagnostics in dump line need to be improved
- *Careful setup of the gun/laser & injector proved to be essential*
- *Vacuum leak was likely caused by thermal cycling of bpm flange from small fractional beam losses*

Correlation of beam loss with energy



Features in Vector Sum and energy profiles

1. Beam turn-on transient not corrected by LLRF regulator
2. Positive slope on Vector Sum, negative slope on energy (VS calibration errors?)
3. Beam loading compensation terminates before end of bunch train causing droop
4. Pulse-to-pulse jitter. Note: shape is very repeatable pulse to pulse
5. Pulses tripped early by MPS cause vector sum to rise up

Planned LLRF improvements...

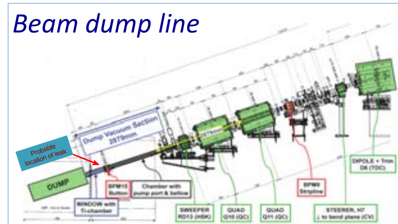
- Increase operational feedback gain... (~20 now, but used >100 during studies)
- Upgrade to latest LLRF system (SimconDSP or ATCA)
- Increase IF to 13MHz or 54MHz
- Automate setup of beam loading compensation parameters
- Generate smoother feed-forward tables
- Optimization of HPRF drive control by cavity phase modulation during filling

Upcoming: 5 weeks of dedicated machine time

- *Tunnel access to repair beam dump vacuum line (3 weeks)*
- *Two weeks of 24/7 dedicated 9mA beam studies*

	Achieved in Sept 08	Goal for Sept 09
Bunch charge	2.5nC @ 1MHz	3nC @ 3MHz
Bunches/pulse	550 @ 1MHz	2400 @ 3MHz
Beam pulse length	550uS	800uS
Beam power	6kW (550x3nC/200mS @ 890MeV)	36kW (2400x3nC/200mS @ 1GeV)
Gradient in ACC4-6	Ensemble avg: ~19MV/m	Ensemble avg: to ~27MV/m Single cavities: to ~32MV/m

Beam dump line



New diagnostics...

- Extend Cerenkov fibers from ID line
- Two new discrete Cerenkov fibers
- New long ionization chamber BLMs
- New diamond bpm on window
- New in-air bpm after window
- Move existing BPM15 upstream

Studies aims for September 2009

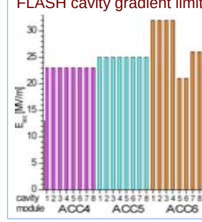
- *Get as close as we can to the ILC-like beam parameters*

Then begin specific targeted studies...

- Energy stability studies with full beam loading
  - Impact of running close to saturation on klystron
  - Impact of running close to quench
  - Operation close to zero–crossing (ILC RTML studies)
- RF power overhead with full beam loading
  - Power overhead needed to meet spec over extended periods
  - How effectively we can minimize static detuning errors
  - How effectively piezos can compensate Lorentz-force detuning
  - How close to saturation before klystron linearization no longer works
- Gradient studies
  - How close to quench can we operate reliably?
  - Running close to quench and with full beam loading
- HOM cryo load with full beam loading (parasitic)

Gradient studies: extrapolating to ILC gradients

FLASH cavity gradient limits



- ILC nominal operating gradient: 31.5MV/m
- FLASH estimated maximum gradients assuming no operating margin
  - ACC4-6 average gradient: ~24MV/m
  - ACC6 maximum (optimized coupling): ~27MV/m
  - ACC6 Cavities 1-4 (optimized coupling): ~32MV/m