

Potential and challenges of superconducting Linac-based FELs

Bob Rimmer, JLab
(outline only)

Why SRF?

Why SRF for future light sources?

- CW or high duty factor beam (kHz-GHz bunch rate)
- Or higher gradient pulsed (ILC-like) or anything in between (flexibility within cryogenic envelope)
- Large aperture for reduced wakefields
- Improved efficiency
- Stability over long and short timescales

Typical parameters

- Frequency 1.3 – 1.5 GHz (could be lower?)
- 16-20 MV/m CW (~10 MV/m real estate gradient, 60% packing factor, JLab upgrade type)
- 25-35 MV/m pulsed (ILC type, slightly better packing factor, ~20 MV/m real estate gradient?)
- $Q_0 \sim 10^{10}$ at 20 MV/m (has been demonstrated)
- Cost ~\$2.6M*/100 MeV (JLab 12 GeV upgrade CW module)
- RF ~\$1.7M/zone (~1mA) (n.b.: 1mA x 10 GeV=10 MW!)
- 2K Cryogenic plant ~\$30M/GeV CW(CEBAF upgrade costs)
- 7.3 cents/volt or \$730M/10 GeV excluding tunnel etc.

*FY08 dollars, beware of inflation!

Options

- CW vs. long pulse (trade off within constant cryo envelope).
- Recirculation vs. 1-pass
 - Cost of arcs vs. Linac
 - Emittance preservation in bends is a challenge
 - Increased effective beam current in linacs
 - Beam loading
 - Beam break up (BBU)
- Energy recovery (same direction or opposite direction)
 - Demonstrated at 10 mA in JLab FEL and at 1 GeV in CEBAF energy recovery experiment.
 - Only cost effective option for high current (e.g. 100 mA) at high energy.

Challenges 1

- Gradient (cavity and real-estate)
- Cryogenic efficiency (Q_0 , R/Q , packing factor, cryo plant, operating temp)
 - Low-loss shapes
 - “superstructure”
 - Large grain material
 - Electropolishing
- Cryomodule cost: room for improvement?
 - Most of the cost is in things other than cavities

Challenges 2

- RF source
 - IOT vs. klystron
- LLRF
 - ✓ Digital (of course? Some stalwarts still prefer analog)
 - ✓ Control algorithm GD, SEL, vector sum?
 - ✓ Stability requirements ($\sim 10^{-4}$ A&P, I&Q?)
 - ✓ Microphonics control via Piezo feedback

All have been demonstrated individually (e.g. Cornell LLRF test at Jlab)

- RF overhead for transient beam loading at high current (e.g. ERL laser on/off produces step change in phase)

Challenges 3

- Generation and preservation of low emittance beams
 - Source, source, source!
 - DC gun: gradient, (6-10MV*/m) cathode lifetime (vacuum 10^{-11} Torr?)
 - RF gun: gradient (~ 20 MV/m* CW), cathode lifetime (vacuum?), cooling
 - SRF gun: (40-60 MV/m*) cathode material (Pb?), particulate contamination
 - Drive laser for high average current (especially if UV)
 - CSR, LSC, BBU etc.

Almost anything you do to the beam can spoil the emittance!

*gradient projections are authors personal opinion

Conclusions

- SRF technology is mature for large projects (CEBAF, SNS, FLASH/XFEL, ILC, Project X, FRIB etc.).
 - Multi-GeV CW or high rep-rate beams are achievable.
 - CEBAF with a suitable radiator would be a world class fourth generation light source!
 - Cost is bearable (?) and has potential to come down.
 - Generation and preservation of low emittance beams is difficult.
 - Challenges are mainly in cost & complexity, not feasibility
 - Source(s)
 - Higher gradient at higher Q_0 (I.e. SRF *optimized for light sources*)
 - Parameters must be driven by user requirements.
- \$\$\$ Investment in key technologies should be made now to further reduce cost and technical risk (especially sources & SRF)

