CLIC Feasibility Demonstration at CTF3

Roger Ruber
Uppsala University, Sweden,
for the CLIC/CTF3 Collaboration

http://cern.ch/clic-study

LINAC’10 – MO303
13 Sep 2010
The Key to CLIC Efficiency

- NC Linac for 1.5 TeV/beam
  - accelerating gradient: 100 MV/m
  - RF frequency: 12 GHz
- Total active length for 1.5 TeV: 15 km
  → individual klystrons not realistic
- Two-beam acceleration scheme

- Luminosity of $2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - short pulse (156ns)
  - high rep-rate (50Hz)
  - very small beam size (1x100nm)

- 64 MW RF power / accelerating structure of 0.233m active length
  → 275 MW/m
- Estimated wall power 415 MW at 7% efficiency

<table>
<thead>
<tr>
<th>Main Linac</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C.M. Energy</td>
<td>3 TeV</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>$2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>Beam Rep. rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Pulse time duration</td>
<td>156 ns</td>
</tr>
<tr>
<td>Average gradient</td>
<td>100 MV/m</td>
</tr>
<tr>
<td># cavities</td>
<td>2 x 71,548</td>
</tr>
</tbody>
</table>
CLIC Layout

Drive Beam Generation Complex

Main Beam 3 TeV (CM)

Drive Beam

Main Beam Generation Complex

- 797 klystrons
- 15 MW, 139 μs
- drive beam accelerator
- 2.38 GeV, 1.0 GHz
- 2.5 km
- delay loop
- CR1
- CR2
- 24 sectors of 876 m
decelerator
- 797 klystrons
- 15 MW, 139 μs
- drive beam accelerator
- 2.38 GeV, 1.0 GHz
- 2.5 km
- delay loop
- CR1
- CR2
- 24 sectors of 876 m
decelerator

- BC2
- TA
- e⁻ main linac, 12 GHz, 100 MV/m, 21.02 km
- 48.3 km
- 75 km
- e⁻ main linac, 12 GHz, 100 MV/m, 21.02 km
- IP
- 2.75 km
- BDS
- booster linac, 6.14 GeV
- BC1
- e⁻ injector, 2.86 GeV
- e⁻ PDR
- 398 m
- e⁻ DR
- 421 m
- e⁻ PDR
- 398 m
- e⁺ injector, 2.86 GeV
- e⁺ PDR
- 398 m
- e⁺ DR
- 421 m
- e⁺ PDR
- 398 m

CR: combiner ring
TA: turnaround
DR: damping ring
PDR: predamping ring
BC: bunch compressor
BDS: beam delivery system
IP: interaction point
dump
CLIC Two-beam Acceleration Scheme

**Drive Beam Accelerator**
- efficient acceleration in fully loaded linac

**Delay Loop (2x)**
- gap creation,
- pulse compression & frequency multiplication

**Combiner Ring (4x)**
- pulse compression & frequency multiplication

**Combiner Ring (3x)**
- pulse compression & frequency multiplication

**RF Transverse Deflectors**

**RF Power Source**

**Drive Beam Decelerator (24 in total)**

**Drive beam time structure - initial**
- 240 ns
- 140 µs total length - 24 x 24 sub-pulses - 5.2 A
- 2.4 GeV - 60 cm between bunches

**Drive beam time structure - final**
- 240 ns
- 5.8 µs
- 24 pulses - 100 A - 2.5 cm between bunches

Roger Ruber (Uppsala University) - CLIC Feasibility Demonstration at CTF3
CLIC Test Facility CTF3

- **Drive beam generation**, with
  - appropriate time structure, and
  - fully loaded acceleration
- **Two-beam acceleration**, with
  CLIC prototype (TBTS)
  - accelerating structures
  - power production structures (PETS)
- **Deceleration stability** (TBL)
- **Photoinjector** (PHIN)
Recombination Principle

Acceleration 3 GHz

Deflection 1.5 GHz

180° phase switch in Sub-Harmonic Buncher

Delay Loop

DRIVE BEAM
LINAC
CLEX
CLIC Experimental Area
DELAY
LOOP
COMBINER
RING
10 m
4 A – 1.2 ms
150 Mev
32 A – 140 ns
150 Mev

RF deflector

Combiner Ring
4th Turn

Initial time structure

1.12 μs total length - 8 sub-pulses - 4 A
110 MeV - 20 cm between bunches (1.5 GHz)

Final time structure

140 ns

140 ns

1.2 s

1 puls - 28 A - 2.5 cm between bunches (12 GHz)
0.8 Hz repetition rate

Roger Ruber (Uppsala University) - CLIC Feasibility Demonstration at CTF3
LINAC’10 - MO303 (13-Sep-2010)
Bunch Re-combination DL + CR

- **Streak camera images from CR**
- bunch spacing:
  - 666 ps initial
  - 83 ps final
- circulation time correction by wiggler adjustment

**Signal from BPMs**

![Graph showing beam current over time](image)

Roger Ruber (Uppsala University) - CLIC Feasibility Demonstration at CTF3
Ongoing Work

- **Beam current stabilization**
  - CLIC requires stability at 0.075% level
  - ok from linac and DL
  - need improvement in CR

- **Phase stabilization**
  - temperature stabilization
  - pulse compressor cavity

- **Transfer line commissioning**
  - transport losses from CR to experiment hall

<table>
<thead>
<tr>
<th></th>
<th>LINAC</th>
<th>DL</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation</td>
<td>0.13%</td>
<td>0.20%</td>
<td>1.01%</td>
</tr>
</tbody>
</table>

RF phase stability $\Delta \Phi$ along pulse (for different ambient temperatures)

Klystron off
Two-beam Test Stand

Spectrometers and beam dumps

Construction supported by the Swedish Research Council and the Knut and Alice Wallenberg Foundation

Experimental area

CTF3 drive-beam

CALIFES probe-beam
Two-beam Test Stand Prospects

**Versatile facility**
- two-beam operation
  - 28A drive beam [100A at CLIC]
  - 1A probe beam [like CLIC]
- excellent beam diagnostics, long lever arms
- easy access & flexibility for future upgrades

**Unique test possibilities**
- power production in prototype CLIC PETS
- two-beam acceleration and full CLIC module
- studies of
  - beam kick & RF breakdown
  - beam dynamics effects
  - beam-based alignment
First Trial Probe Beam Acceleration

- Fine tuning DB↔PB timing
  - **3GHz phase scan klystron**
  - coherent with 1.5GHz laser timing signal

- ~6 MeV peak-to-peak
  - zero crossing: 177 MeV, 205 degr.
  - phase scaling: 5.58 (expect 4x)

- Optimize
  - PB energy spread & bunching
  - klystron pulse compression
  - coherency klystron and laser
  - low input power (ACS not conditioned)
Energy loss estimation

→ mismatch black-green due to phase variation along pulse

Improve by incorporating incoming beam info
Conditioning Process

Present stable level:

• PETS + recirculation loop
  – ~70 MW peak power,
  – ~200 ns pulse

• Accelerating structure
  – ~23 MW peak power
Example RF Breakdowns

PETS recirculation loop

3 consecutive pulses

Roger Ruber (Uppsala University) - CLIC Feasibility Demonstration at CTF3

LINAC’10 - MO303 (13-Sep-2010)
CTF3 Experimental Program

• Two-beam acceleration
  – conditioning and test PETS and accelerating structures
  – breakdown kicks of beam
  – dark (electron) current accompanied by ions
  – install 1, then 3, two-beam modules

• Drive beam generation
  – phase feed forward for phase stability
  – increase to 5 Hz repetition rate
  – coherent diffraction radiation experiments

• Drive beam deceleration
  – extend TBL to 8 then 16 PETS
  – high power production + test stand

• 12GHz klystron powered test stand
  – power testing structures w/o beam
  – significantly higher repetition rate (50 Hz)

TBTS is the only place available to investigate effects of RF breakdown on the beam
Conclusions

• Reached first milestones:
  – Drive beam generation with appropriate time structure and fully loaded acceleration.
  – Two-beam acceleration with CLIC prototype structures.

• Continued operation:
  – Optimize beam and two-beam acceleration.
  – Investigate RF breakdown effects on beam.

• Planned enhancements:
  – 12 GHz klystron powered test stand
  – Install full two-beam test modules.

Many thanks to all colleagues, their work and their suggestions!