COMMISSIONING OF THE SRF LINAC FOR ARIEL


TRIUMF Canada's National Laboratory for Particle and Nuclear Physics,
Vancouver, BC V6T 2A3, Canada
The ARIEL E-Linac SRF specification – dominated by RF beam loading
- 10mA at 50MeV - 0.5 MW CW
- CPI 75kW VWP 3032 coupler to deliver 50kW CW -> 10 couplers
- 2x 50kW couplers per cavity -> 5 cavities
- 10MeV energy gain per cavity
- 10W at 2K -> Qo=1e10
- Reduce trapped HOMs
- Large (90mm) single chimney sufficient for CW operation up to 50W
- One cavity in ICM and 2 in ACM

![Diagram of E-Linac SRF specifications](image)
E-Linac Accelerator Vault – Phase I
Cavity Design

<table>
<thead>
<tr>
<th></th>
<th>TRIUMF</th>
<th>DESY</th>
<th>TRIUMF/DESY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency [MHz]</td>
<td>1300</td>
<td>1300</td>
<td>-</td>
</tr>
<tr>
<td>$R_{sh}/Q$ [Ohm]</td>
<td>1000</td>
<td>1030</td>
<td>3% less</td>
</tr>
<tr>
<td>Geometric factor $G$ [Ohm]</td>
<td>290</td>
<td>270</td>
<td>7% more</td>
</tr>
<tr>
<td>$E_p/E_a$</td>
<td>2.1</td>
<td>2.0</td>
<td>5% more</td>
</tr>
<tr>
<td>$B_p/E_a$ [mT/(MV/m)]</td>
<td>4.4</td>
<td>4.2</td>
<td>5% more</td>
</tr>
<tr>
<td>Cell coupling [%]</td>
<td>2.0</td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>

TRIUMF e-LINAC cavity is similar to 1.3GHz 9 cell DESY TESLA cavity. 2 symmetrically opposed 75kW CPI couplers.

4 9-cell cavities fabricated at PAVAC

P. Kolb, et al., “HOM Measurements on the ARIEL eLINAC Cryomodules”, MOPB088, SRF2015
The CPI VWP 3032 75kW CW Coupler

**Handling**
- Assembly in clean room
- Keep sealed with filtered N2 gas

**Baking**
- 100C 7 days
- 10C/hour
- N2 filtered gas flow to ‘warm’ assembly

RF Conditioning
• TW CW up to 19.5kW - takes 3-5 days
• SW Pulse mode
  • Variable short plate in 3 positions (to move SW along the couplers)
  • Pulse with duty factor 1% 10 Hz power up to 10kW – (equivalent 40kW in TW) – 3 days

4 power couplers have been installed to the cavities in ARIEL ICM and ACM cryomodules for beam commissioning at TRIUMF
Houses

- one nine-cell 1.3GHz cavity
- Two 50kW power couplers

Features

- 4K/2K heat exchanger with JT valve on board
- Scissor tuner with warm motor
- LN2 thermal shield – 4K thermal intercepts via syphon
- Two layers of mu-metal
- WPM alignment system
Injector Cryomodule

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Features
- 4K/2K heat exchanger with JT valve on board
- Scissor tuner with warm motor
- LN2 thermal shield – 4K thermal intercepts via syphon
- Two layers of mu-metal
- WPM alignment system
• The ACM uses same basic design as ICM but with two 1.3GHz nine cell cavities each with two 50kW power couplers

• There is one 4K/2K insert identical to the ICM

Cryogenics

- 4K liquid at 1.3 Bar delivered in parallel to cryomodules from supply dewar
- 4K levels are regulated by LHe supply valve
- 2K levels are regulated by JT valve in each CM
- 2K pressure is regulated by 2K exhaust valve on each CM and trunk valve upstream of SA pumps
For Phase I we specify two 290 kW CW CPI VKL7967A klystrons with 65 kV, 10 A DC AMPEGON power supply (KPS).

In the future, for Phase II one of these klystrons will drive next cryomodule.

We are looking for a cost effective 1.3GHz power source at ~150kW for the ICM.
The heterodyne technique of up and down converter is chosen to manipulate the 1.3GHz frequency and the intermediate frequency (IF) of 138MHz for RF signal processing.
- 650MHz e-Gun
- two 1.3GHz NC
- ICM 1.3GHz SC
- ACM 1.3GHz SC

Feedforward system for high current beam acceleration is under development.
Cryomodule strategy

- Jacket and install ARIEL1 cavity in ICM
- Jacket and install ARIEL2 cavity in ACM together with a dummy cavity
- ACMuno
  - Dummy cavity has all interface features including helium jacket and DC heater
  - All helium piping and beamline interconnects will be final
  - ACMuno allows a full cryogenics engineering test plus two cavity beam acceleration to 25MeV
- Installed the cryomodules for a combined beam test in Sept. 2014 – cryogenic engineering and funding milestone
ICM and ACMuno Assembly

Assembly of both CMs proceeds through summer of 2014

ICM top assembly

ACMuno assembly

ACMuno – ready for cooldown Sept. 1
RF System modification
• ‘Dummy’ waveguide branch of variable power divider has been terminated with RF load
• The variable power divider has been tuned for full transmission to the Cavity waveguide branch
High Power RF Installation

• Installed
  • Two CPI 290kW CW 1.3GHz klystrons
  • Two 600kW 65kV klystron power supplies from Ampegon

• Each klystron reaches specification at the factory

• At TRIUMF – tests were limited by available load or circulator – one was operated to 250kW CW the other to 150kW CW

• Delivered power into a cold cavity – 25kW pulsed and 18kW CW
Cryomodule Protection System has been developed

ICM Cold test results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>4K static load (no syphon), W</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4K static load with syphon, W</td>
<td>6</td>
<td>6.5</td>
</tr>
<tr>
<td>2K static load, W</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>77K static load</td>
<td>100</td>
<td>&lt;130</td>
</tr>
<tr>
<td>2K production efficiency</td>
<td>82%</td>
<td>86%</td>
</tr>
</tbody>
</table>

- Cryogenic engineering matches design expectations
- Syphon loop performance characterized – works well – optimized in off-line cryostat tests
ACMuno First Cold test results

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<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>4K static load with syphon, W</td>
<td>7</td>
<td>6.4</td>
</tr>
<tr>
<td>2K static load, W</td>
<td>7</td>
<td>6.5</td>
</tr>
<tr>
<td>77K static load, W</td>
<td>100</td>
<td>TBD</td>
</tr>
<tr>
<td>2K production efficiency</td>
<td>82%</td>
<td>TBD</td>
</tr>
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- Cryo-engineering looks good – static loads as expected – cooldown straightforward
- Initial RF tests – CW performance limited to 7MV/m and pulsed performance to 10MV/m by multipacting in couplers – no field emission to 10MV/m

ICM System Performance & Acceleration

- All systems functional
  - HLRF, LLRF, tuner, power couplers
  - Cavity phase lock is stable – couplers balance – rf protection in place
  - Confirmed tuning range – 400kHz

- Measured microphonics – very stable

- Successful acceleration achieved – confirms rf integration and calibration

ICM and ACMuno Measured Q-values

![Graph showing measured Q-values for ICM and ACMuno at different Ea, MV/m. The graph includes a comparison with performance specification and data points for 10W and 20W.]
ICM and ACMuno gradient

ICM cavity ok!

Two rf systems ready!

Achieve 23MeV

P-forward (kW)
Ea (MV/m)
y = 0.1066x^{2.0606}

ACMuno

P-forward (kW)
Ea (MV/m)

ICM

ICM and ACMuno gradient
Progress in SRF Systems in 2014

- Cryogenics acceptance tests complete
- Two klystrons and HV supplies installed and commissioned
- ICM and ACMuno assembled, installed and commissioned
- First beam acceleration demonstrated
The ICM and ACMuno cold tests have demonstrated that the cryo-engineering is robust and matches specifications.

ICM and ACMuno cavities meet specifications

- Plan to operate each cavity at 13MV/m for 25MeV beam tests through to the end of 2015
- Assemble ICM for VECC in Kolkata and install it online to confirm performance
- Install 2nd cavity in ACM and run beam tests through the end of 2016
Thanks!

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