The 1.3 GHz SRF injector cryomodule for VECC - designed and manufactured at TRIUMF

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Outline:

March 08, 2016 ICEC-ICMC2016, New Delhi, India

Introduction

• ARIEL project
• e-linac
• Injector Cryomodule
• 4K/2K cryogenic insert
• Cryogenic insert test
• Test insert overview
• Test diagnostics
• 4K/2K Test results
• Syphon loop performance

Summary
State of TRIUMF

The state of the laboratory is strong!

Owned & operated by a consortium of
19 universities

- 12 MEMBERS
- 7 ASSOCIATE MEMBERS

March 08, 2016

ICEC-ICMC2016, New Delhi, India
The 530 MeV Cyclotron at TRIUMF: The World’s Largest Cyclotron

Built in 1972
- Tank and lid complete, some internals complete
- ARIEL3 cavity 2K qualification – in progress
- ICM2 hermetic unit assembly – Dec 2014
- 4K/2K fabrication – Oct 2014
- Top assembly complete – Jan 2014
- 2K tests in ISAC-II clean room – Jan/Feb 2014
- Beam test in e-hall – March 2015
- Ship to VECC
TRIUMF and e⁻-linac

- Electron driver for photo-fission: independent and complementary to 500 MeV cyclotron
  - Composed of five elliptical cavities at 1.3 GHz
  - Final specification 50 MeV/10mA ->0.5 MW beam power, cw – by 2018 (cash flow dependent)
- Injector cryomodule (ICM 1) - designed, built and tested as part of ongoing collaboration with VECC- 2013
- Staged installation: 25-30 MeV and 3 mA - 2014
- Injector cryomodule (ICM 2) - designed, built and tested as part of ongoing collaboration with VECC- 2016
Injector Cryomodule

Houses
- one nine-cell 1.3GHz cavity
- Two 50kW power coupler

Features
- 4K/2K heat exchanger unit with JT valve on board – expand LHe from 1.2bar to 30mbar
- Scissor tuner with warm motor
- Two layers of mu metal – warm and cold
  - WPM based alignment
  - Stainless steel ribbed tank with hatches for access
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Cryogenic Circuits

- Cryogenic insert with 4K phase separator JT valve and heat exchanger on board to produce 2K liquid
  - Allows stand alone testing from any 4K refrigerator
  - Insert is removable with cryomodule in situ
- 4K intercepts cooled by siphon circuit from 4K reservoir
  - Cooldown circuit for initial cooling
  - LN2 cooled thermal shield
Cryoinsert design

- Design enables prototyping and testing of cryoinsert in existing test cryostat
- 4k supply valve regulates 4K level
- JT valve regulates 2K level
- 2K exhaust valve regulates 2K pressure (temperature)
TRIUMF’s ISAC SRF Cryogenics Upgrade
TRIUMF’s ISAC SRF Cryogenics Upgrade
TRIUMF’s ISAC SRF Cryogenics Upgrade

- BUSCH – Combi DS3010-He
- Roots blower & screw type backing pump
- 4 pumps delivered 2013 March 15
- 1 unit installed at VECC for test
Cryogenic insert Design

4K/2K cryoinsert

Cryoinsert was tested in the test cryostat before installation in the cryomodule

2K Test Load

141MHz Test Cryostat

Injector Cryomodule

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Cryogenic insert Design

Injector Cryomodule

4K/2K cryoinsert

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2K Test Load

141MHz Test Cryostat
Establish and regulate levels and temperatures in both 4K and 2K reservoirs

Set calibrated heater power in 2K reservoir

Close 4K supply valve and record falling level

Record 4K falling level for various heater settings up to maxim mass-flow rate for 2K pumps
4K/2K Diagnostics

- Temperature sensors – 6 diodes and 2 CERNOX
- Level probes – one each for 4k and 2k reservoirs
- Heaters – one for each reservoir and one for each siphon load
The Syphon loop cooldown interface flange

Objective was to optimize the choice of materials, joint technology, dimensions, parallel loop interference.

Temperature sensor

LHe tube

Heater

Temperature sensor

add heater power ----nucleate boiling --- density of two-phase liquid decrease---flow
The critical heater power is about 2W for total nucleate boiling.

\[ q_{cr} \left[ \frac{W}{cm^2} \right] = \frac{1}{1.7 + 0.125(L/D)^{0.88}} \]

- \( L \) - length = 48 cm
- \( D \) - diameter = 0.78 cm
- \( A \) - area = 12 cm\(^2\)

\[ \therefore Q_{cr} \approx 2 \text{ W} \]

4K/2K siphon circuit test results

- **Test 1**
  - Measured 4K siphon circuit efficiency – extra heat load caused by convection in 4K reservoir ~15-20W
- **Test 2** – after modifying siphon circuit
  - Siphon loop now well behaved with static load of 1.6W

Additional siphon exhaust guidetube and Teflon funnel in 4K reservoir drastically drops convective load
4K/2K siphon circuit test results

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- **Graph:**
  - After modification
  - Before modification

- **X-axis:** Heater power (siphon) (W)
- **Y-axis:** 4K static load (W)
4K/2K Cryogenics unit test summary

- **Test 1**
  - Measured static load of 4K (2W) and 2K (0.5W) reservoirs
  - Measured efficiency of 2K conversion of 66% at 0.5 g/s mass flow
  - Measured 4K siphon circuit efficiency – extra heat load caused by convection in 4K reservoir ~15-20W

- **Test 2** – after modifying siphon circuit
  - Siphon loop now well behaved with static load of ~1.6W

- Proved the concept in large
- Have established the dimensional parameters for syphon loops
- Narrowed down materials choice and joints type
- Verified the absence of cumulative negative effects of parallel syphon circuits on cryoinsert performance
The cavity was then assembled in the clean room and prepared for cold test in the new multi-cell cryostat.

The test confirmed the operation of the cryostat (vacuum, diagnostics, static load) and rf system (rf variable coupler and cables).
Outline of e-Linac cryogenic system
ICM1 Assembly

ICM mock-up – 2013

• Mock-up assembly of ICM used to test parts and procedures

• Final assembly (aided by lessons learned from mock-up) - completed in <1 month

Cavity hermetic unit (March 14, 2014)

Top assembly into tank

ICM top assembly

ICM unit Complete (April 9, 2014)
ICM1 Cold test results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated</th>
<th>Measured</th>
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<tbody>
<tr>
<td>4K static load (no syphon)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4K static load with syphon</td>
<td>6</td>
<td>6.5</td>
</tr>
<tr>
<td>2K static load</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
ICM2 Assembly

ICM2 Buttoned Up (Feb, 2016)
ICM 2 Cold test, Cold Alignment, Transfer to e-Hall, RF tests, Beam tests, etc.
ICM2 Vacuum Leak test (Last week)
Today and forward
ICM Cryogenic Design Summary

• The 4K/2K cryogenic insert assembly has been tested successfully and proved for installation in the ARIEL Injector cryomodule.

• The static load of the system has been measured.

• The Maximum 2K production efficiency is about 77% for 1.1gm/sec mass flow.

• Siphon loop performance has been improved by adding a funnel loop in 4K reservoir to reduce the convection load.
The 2K/4K cryoinsert tests have demonstrated the validity of our design approach.

The ICM1 and ACM Uno cold tests have demonstrated that the cryo-engineering is robust and matches specifications.

Having e-Linac infrastructure in place saves time and efforts on the test infrastructure for ICM2.

Plan to accomplish the cold test, RF test and the beam test for ICM2 in nearest few months.
Thank you!

Merci!