SRF Developments at TRIUMF

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Outline

• SRF program at TRIUMF

2008-2013 Highlights
  • ISAC-II completion
  • E-Linac development
  • Fundamental SRF development
  • Industrial partnerships

2015-2020
  • ARIEL-II completion
  • ISAC-II upgrade
  • Fundamental SRF development
  • Industrial partnerships

Summary
SRF at TRIUMF
• SRF at TRIUMF began in 2000 with cavity and infrastructure development in support of the ISAC-II heavy ion linac.

• SRF group evolved into SRF/RF department, initiated in 2008
  – Supports Operations, internal projects (ISAC-II, ARIEL), plus SRF/RF R&D (student education), local industry (PAVAC) and external collaborations

• SRF is a recognized core competence of TRIUMF (SRF2015 workshop will be hosted by TRIUMF)
The SRF/RF Department comprises expertise in superconducting rf, high power rf and low level rf

Currently the Department has 24 members
- 8 professionals
- 11 technicians
- 2 post-docs
- 5 students
• ISAC-II building houses the SRF test and assembly areas (legacy of ISAC-II installation)

  • 500m² of floor space
  • Ultrasound cleaning tanks, High Pressure Water Rinse area, shielded rf test area, cryomodule assembly area, chemical etching lab
  • Over 100 single cavity tests performed and eight cryomodules assembled since 2004
Highlight #1 - ISAC-II Completion

- ISAC-II Phase II completed on time and on budget (7.5M$ project)
- April 2010 - $^{16}\text{O}^{5+}$ accelerated to 10.8MeV/u equivalent to 6.5MeV/u for $A/q=6$ (meets ISAC-II original specification on first acceleration)
- Enables acceleration of all ISAC ions above Coulomb barrier
- First heavy ion linac to utilize clean assembly techniques - set a new performance mark for a cw low beta sc-linac with $E_p>30\text{MV/m}$
- ISAC I/II – leading RIB post-accelerator in the world due to flexibility and performance
Phase I
SCB 2006
5 CM’s
4cav/CM
Veff=20MV

Phase II
SCC 2010
3 CM’s
6+6+8
cav/CM
Veff=20MV

ISAC-II SC-Linac
Highlight #2 – SRF@PAVAC

• PAVAC Industries of Richmond BC are experts in forming, machining and electron beam welding – a major product is the design and manufacture of EBW machines

• TRIUMF began collaborating with PAVAC in 2005 and produced the first made in Canada superconducting accelerating cavities in 2007

• In total 22 ISAC-II Phase II cavities were supplied by the PAVAC/TRIUMF joint effort by 2009
Partnership with PAVAC has grown from producing the ISAC-II QWRs to developing quality rf resonators and accelerator technology for TRIUMF and global collaborators.

PAVAC/ TRIUMF tandem are now producing cavities for:
- ARIEL plus VECC (India), FNAL, FRIB (USA), IHEP (China), RAON (Korea)

PAVAC has grown since 2005 from 10 employees to >50 from 3000 sq ft to 30000 sq ft (and now moving to 100000 sq ft)
• The ARIEL e-Linac requires one nine-cell in the injector section and four nine-cell cavities in the accelerator section.

• TRIUMF SRF / VECC (Kolkata) are collaborating on the design and test of the Injector Cryomodule (ICM) to be used as a working prototype for Accelerator Cryomodule (ACM).
  - Two ICM’s are being built and tested with beam - one for TRIUMF and one for VECC.
Existing lab space in ISAC-II used for a beam test of the front end of e-Linac with a 30kW rf source

E-Gun
- 100kV gun tests completed in April 2013
- 300kV gun now nearing completion

LEBT fully commissioned

MEBT test line being assembled

ICM in assembly

Two cavities in hand

30kW IOT running routinely – power coupling conditioning complete (2)
Longitudinal Diagnostics

- A 1.3GHz TM110-like mode deflecting cavity
- Deflector installed on analyzing leg to investigate beam bunch characteristics*
- Beam deflection gives longitudinal emittance information

Design of ARIEL Cryomodule

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

Features
• Top loading box design
• 4K/2K heat exchanger with JT valve on board – expand LHe from 1.4bar to 30mbar
• Scissor tuner with warm motor
• Two layers of mu metal – warm and cold
• LN2 thermal shield
• CESIC HOM damping material in warm/cold transition
• WPM based alignment
• Stainless steel ribbed tank with hatches for access
A mock-up of the injector cryomodule is being assembled to pre-test all components prior to final assembly.

- **Support Towers:**
  - Assembled and installed

- **Lid:**
  - Leak checked with tank and installed.

- **Strut and Strong-back:**
  - Fully assembled and integrated with lid and cavity.

- **2K Reservoir:**
  - Leak checked and installed.

- **Cold Tuner:**
  - Tested and assembled into Mock-up.

- **Warm Tuner:**
  - Tested and assembled and integrated with cold tuner.
Developed infrastructure to process and test 1.3GHz single cell then multi-cell cavities and support ARIEL cryomodule production.

- Cavity tuning stand
- Power coupler conditioning station
- Single cell cryostat
- Multi-cell cryostat
- BCP chemical etching
- High pressure water rinse
- TR-PAV2 cavity test

TR-IPR Accelerator Breakout - Laxdal
• BBU analysis defines the criteria of \((R_d/Q) \cdot Q_L < 10^7\)
• Modeled nine-cell cavity in CST
  - trapped mode at 2.56GHz TE111 dipole mode with \(R_d = 3 \times 10^7 \Omega\)
  - Asymmetric beam pipes push trapped mode towards the tuner end
  - Use damping material CESIC to damp dipole modes*

*P. Kolb, R.E. Laxdal, V. Zvyagintsev, Y.C. Chao, B. Amini, `Cold Test Results of HOM Absorber Material for the ARIEL eLinac at TRIUMF’, published in NIMA (PhD student research)
• Two cavities have been delivered from PAVAC – two more in fabrication – due Nov. 30 and Jan 30

• ARIEL1 and ARIEL2 have been cold tested

• ARIEL1 sent to FNAL for degassing

• Utilizing `smart bell’ fabrication strategy

Equator welded from the inside, iris from outside
Highlight #4 - SRF Student program

• TRIUMF is now offering a graduate students program in Accelerator Physics and Engineering
• One course per year taught at UBC by TRIUMF research scientists
• Four PhD students, three post-docs and >10 undergraduates in SRF studies to date.
• NSERC grant – 60k$/year for five years from 2012
• Anna wins 2013 IEEE PAST Doctoral Student Award
  • ‘to recognize significant and innovative technical contributions to the field of particle accelerator science and technology as demonstrated in a student’s doctoral thesis’

• Thesis title `Field-dependent Losses in Superconducting Niobium Cavities’

SRF in 2015-2020
ARIEL e-Linac Completion

- Complete second accelerating module to complete e-Linac
  - Fabricate, process and test two more cavities
  - Fabricate and assemble EACB
  - Utilize internal developments and collaboration on high Q with FNAL and others to optimize performance
Heat treatment – Phase I

- Resistive wall losses in rf cavities are a major cost driver for continuous wave (cw) SRF linear accelerators.
- Recent advances in reducing surface resistance with a combination of UHV heat treatments, plus doping with N2 and Ar, and surface processing.
- NSERC grant is being used to fund an rf induction oven to (initially) optimize the heat treatment and doping study of a 1.3GHz single cell cavity.
- Status - All purchased parts in hand and other components being fabricated.


Many cw hadron linacs are now in development – surface resistance for low frequency cavities is an issue.

We propose to build two multi-mode TEM cavities (QWR, HWR) to study the rf surface resistance as a function of rf field, temperature and rf frequency.

Each cavity is sized to fit into the rf induction oven to study the effect of heat treatments as a function of rf frequency.


ISAC-II High Q Upgrade

- ISAC-II superconducting heavy ion linac was installed in two phases with 20 cavities installed in 2006 and 20 cavities installed in 2010

- ISAC-II turned on with highest average gradient of any low beta linac

- Recent progress in SRF community has produced new treatments for reducing residual resistance

- Goal for 2015-2020 is to increase energy reach of ISAC-II by re-treating cavities with new heat treatments and surface processing optimized with the multi-mode resonator and rf induction oven

- Requires new high vacuum furnace
SRF Deflecting Cavity

- A future extension to the ARIEL e-Linac will be the addition of a recirculation loop for an Energy Recovery Linac (ERL).

- The ERL bound beam will be interleaved with the single-pass RIB bound beam utilizing a 650MHz SRF deflecting mode cavity, allowing for simultaneous beam delivery to both ERL and RIB users.

- A novel H-mode ridge and post structure is being developed.
• Continue to exploit TRIUMF’s unique material science diagnostics and local university condensed matter expertise

• Utilize muSR and SQUID magnetometry for Nb and other bulk material properties testing

• Designing new beamline for beta-NMR facility to allow application of strong DC (up to 200mT) and/or RF magnetic fields parallel to a sample

• Will allow implantation of polarized 8Li ions as a local magnetic probe with depth control through the London layer

• Ideal for studying both thin film and bulk Nb performance, as well as new thin or bulk film coatings of alternative superconductors

Proposing to develop a sapphire loaded sample host test cavity to measure rf losses on sample material in synergy with beta-NMR diagnostic
Grow Industrial Partnerships

- Continue to grow partnership with PAVAC

- PAVAC/TRIUMF will continue to develop cavities for external collaborations to expand PAVAC’s expertise and global market share
  - TRIUMF, FNAL, VECC, IHEP, FRIB, RAON

- PAVAC/TRIUMF to move to commercialization of cryomodule technology
  - QWR cryomodule for VECC
  - 2K cryomodules for electron/hadron cw applications (ADS, RISP)
  - Development towards ILC cryomodule production

- Support PAVAC in other initiatives including Electron Beam Flu Gas Treatment

Nov. 16, 2013

IPR Accelerator Breakout - Laxdal
Summary

• SRF at TRIUMF supports internal projects (ISAC-II, ARIEL), student education, local industry and external collaborations

• The goal in the next five year plan is to continue to grow the program through support for internal projects, external industrial investments, NSERC grants and some work for others agreements

• SRF science and technology continues to make significant breakthroughs and the TRIUMF SRF program is well positioned to make valuable contributions and train the professionals in the field
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