SCRF DEVELOPMENT AT TRIUMF

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Abstract

TRIUMF started SCRF development with the superconducting heavy ion linear accelerator project, ISAC-II, in 2000. Since that time much work has been completed for development, prototyping and testing. The ISAC-II project was successfully completed and we now have in operation 40 superconducting bulk Nb QWR cavities assembled in eight cryomodules. The last twenty cavities, just completed, were produced by PAVAC Industries Inc. of Richmond BC; the first superconducting accelerator cavities produced in Canada.

In 2007 TRIUMF started development towards a 50MeV electron superconducting linear accelerator to be used as a driver to produce radioactive ion beams through photofission. The accelerator is based on TTF/ILC elliptical bulk Nb cavities technology.

Results, experience and plans of the SCRF program at TRIUMF will be discussed.

INTRODUCTION

Motivation for SCRF development at TRIUMF was the ISAC-II heavy ion accelerator project started in 2000 and required 20 106MHz medium beta (5.7 and 7.1%) and 20 141MHz high beta (11%) superconducting QWR cavities which provide an accelerating voltage of 40MV. Medium beta cavities were developed in collaboration with LNL and fabricated by Zanon (Italy). Five cryomodules with these cavities were successfully commissioned for operation in April 2006 [1]. High beta cavities were developed at TRIUMF and produced by PAVAC Industries in Canada. Three cryomodules with high beta cavities were successfully commissioned in April 2010 [2]. An SCRF infrastructure for SC development including SCRF test area, clean room and chemical laboratory (Fig. 1) was created at TRIUMF.

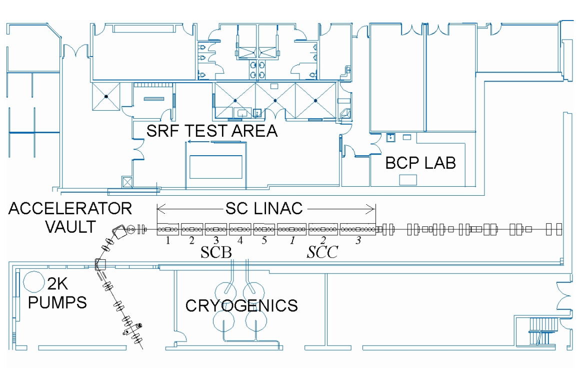

Figure 1: TRIUMF SCRF infrastructure

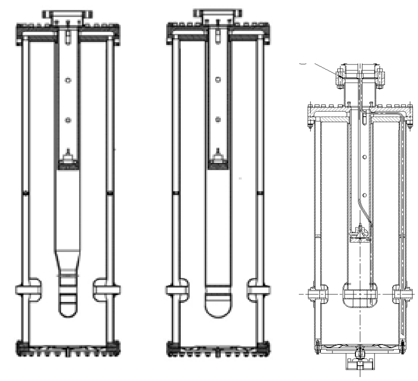

Figure 2: ISAC-II β =5.7,7.1 and 11% cavities

In 2007 TRIUMF has embarked on a 1.3GHz development program to support the construction of a 50MeV 10mA e-Linac for the production of radioactive ion beams through photo-fission. A prototype cryomodule and 9 cell cavity are in conceptual design. Two copper and two niobium single cell test cavities were fabricated, and one copper model of 7 cell cavity is in fabrication at PAVAC Industries.

ISAC-II RESULTS

ISAC-II commissioning and operation results [3] provide an example of bulk Nb QWR cavities in cryomodules with common vacuum. The cavities (Fig.2) are patterned after ALPI INFN-LNL are based on a coaxial line with inner and outer conductors with diameters of 60 and 180mm. The difference between the cavities is in the beam tube region of the inner conductor. The round inner conductor shape of the beta 7.1% 106MHz is modified by squeezing to attain the 5.7% beta cavity. To provide the structure with optimum beta of 11% we went to 141MHz with corresponding decreasing of cavity length. A beam tube is added to improve the transit time factor. All cavities are specified for CW operation at 7W power dissipation with acceleration voltage 1.08MV corresponding to 30MV/m electric and 60mT magnetic peak field. Tuning of the cavities is provided with deformation of Nb plates bolted to the bottom flange. A mechanical damper installed inside of the inner conductor provides >10dB attenuation of microphonics noise. The cavities operate in strong overcoupled regime (coupling ~50-100) to provide enough bandwidth to maintain stable operation from microphonics. The LN2 cooled coupling loop produces <0.25W power dissipation in helium system at 200W forward power. One 9T superconducting solenoid is installed in the middle of each of the eight cryomodules in close proximity to the cavities.

Medium Beta Part (Phase I)

The performance of the SCB cavities is monitored periodically typically during start-up after shutdown (Fig. 3). The linac is warmed up once per year for three months as part of the site maintenance shutdown. In addition several of the cryomodules have been vented (SCB1 for pump replacement) and some have been taken off line (SCB2 and 4) for disassembly to repair internal faults of the coupler loop mechanical joint.

The cavities were tested in a single cavity test cryostat with average result at 7W power dissipation of Ep~37MV/m. After installation in the cryomodules average cavity performance degraded by 10% and is of Ep~33MV/m. Possible reason could be cavities contamination during cryomodule assembling. Individual cavity performance does vary somewhat but the average gradient has been maintained over four years of operation.

In 2010 we lost one cavity#11 (in SCB3 cryomodule) due to failure of the inner coupler cable connection. We already had such a problem in this cryomodule for cavity#9 in 2005 (it was 1st cryomodule in production).

Cavity#5 and #9 have custom frequency compensation puck welded to tuning plate. These cavities after experimental electro-polish had too high frequencies. Compensation puck shifts the cavity frequency down ~100kHz and cause ~30% current density increase in the tuning plate bolted contact.

During operation cryogenics failures caused cavity recoverable degradation.

- Trapped magnetic flux from short interruption of LHe supply [4]. Full recovery (~two hours activity) involves degaussing the solenoid and environs, then warming cavities and solenoid to 30K to quench all solenoid currents, then recooling the cold mass.
- Q-disease due to long interruption of LHe supply. Full recovery requires cavity warmup to room temperature.

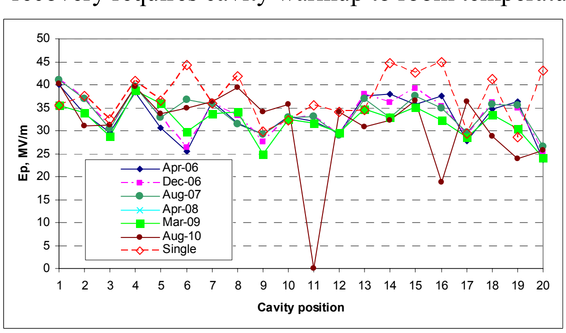

Figure 3: SCB cavities performance at 7W power dissipation over 4 years

Low level multipacting in some cavities is responsible for delay of start-up and tuning. It is three orders of magnitude less than the operational field level and doesn't affect performance. Short pulse RF conditioning is required to start these cavities. Multipacting disappears during cavity operation and reappears after warmup.

The Phase I system uses tube amplifiers and they have been a source of downtime due to tube aging issues causing phase drift and non-linear output affecting LLRF operation. Average tube lifetime is about 10,000 hours.

High Beta Part (Phase II)

After testing of two prototype cavities in 2007 another

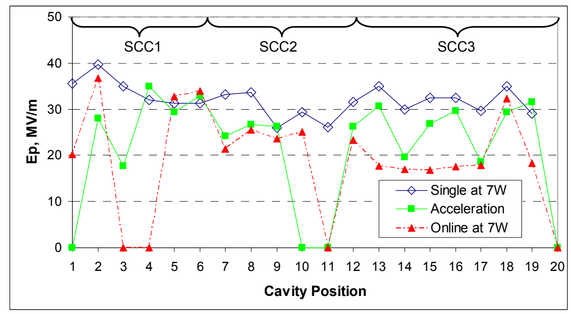

Figure 4: SCC cavities performance in single tests at 7W, 1st acceleration and current 7W levels

20 cavities were ordered from PAVAC in 2008 [5]. Four cavities were rejected due to vacuum leaks that opened in the donut weld after a final BCP of 100µm. Due to the tight schedule we limited BCP (in the beam tube region) to 60µm on subsequent cavities. All leaking cavities were successfully repaired and tested. Due to tight schedule another four cavities were installed in cryomodules without single cavity cryostat tests: three cavities were tested offline in the cryomodule SCC2 and one was installed without any test.

Fig.3 is presenting SCC cavities performance in single (offline) tests, during 1st acceleration commissioning run and recent online performance at 7W power dissipation. Average field in offline tests is 32MV/m, ~15% below Phase I performance. We speculate that this is due to the reduced etching in Phase II. The performance decreased online to 27.6MV/m, a reduction of 16%. The degradation reasons are still under investigation.

- Contamination during installation
- Q-disease. Tests show that SCC cavities start degrading performance after 1h in the range of temperatures 200-100K, for SCB cavities it occurs after 10h. It could be due to higher hydrogen content in the Nb.
- Surface pollution during rf processing
- Trapped flux due to local magnetic field penetration

We started a loop study with two spare SCC cavities to investigate the reasons of degradation and to find the ways to improve the performance [6].

During the SCC cryomodules commissioning we lost four cavities due to failure of coupler inner lines. Indirect data (TDR measurement and vacuum burst during the accidents) show that there are RF shorts formed due to breakdown in the cables. We will work on it during next shutdowns. Since every cavity has an independent RF system, we can compensate the performance of the unavailable cavities by increasing the gradient in other cavities (at power dissipation >7W).

The solid state amplifiers work well and are more stable than SCB tube amplifiers.

SCRF DEVELOPMENT FOR ELECTRON LINAC PROJECT

In 2007 TRIUMF started developments toward an electron driver for photofission (Fig. 5) which will be independent and complementary to the 500MeV cyclotron. The linac is composed of five 9 cell elliptical cavities at 1.3GHz in 3 cryomodules with final goal by 2017 of 50MeV/10mA, 0.5MW beam power, CW operation [7].

Injector cryomodule (ICM) is under design in the collaboration with VECC (India).

The core of the driver is a 9 cell TESLA type cavity with two symmetrically opposed CPI couplers (Fig.6) and should provide at 2K nominal acceleration gradient 10MV/m in CW operation. The cavity is under development and study for higher order mode (HOM) estimations. Future developments may include a recirculating ring so that beam break-up (BBU) is also under study.

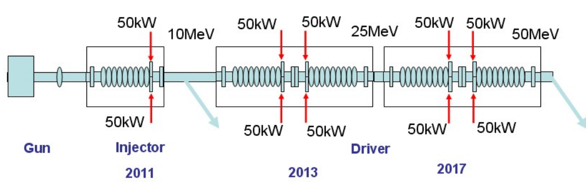

Figure 5: 50MeV e-LINAC layout

PAVAC has produced two copper and two Nb single cell test cavities. In collaboration with University of Toronto the cryostat for vertical tests of 1.3GHz elliptical cavities has been built and tested. Fig.7 shows recent results of the single cell cavity vertical tests at 4 and 2K. There is some improvement in comparison with previous

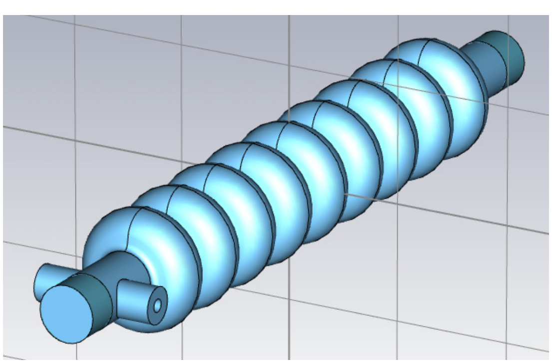

Figure 6: TRIUMF 9 cell cavity CST model

tests but factor at 2K Qo~4*10^9 is still not enough and maximum gradient Ea~7.5MV/m is limited by field

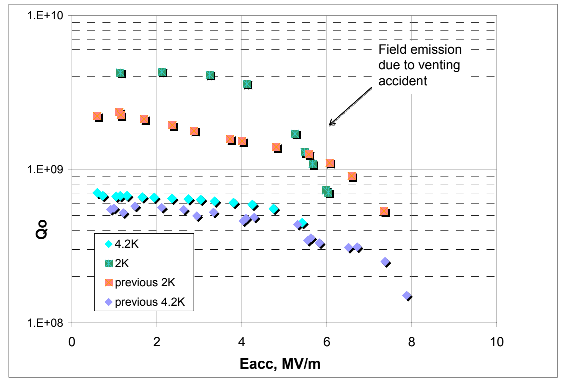

Figure 7: Test results of TRIUMF single cell cavity

emission due to a venting accident during cavity test preparation. We already have done another etching and prepared the cavity for the next test.

Fabrication of a 7 cell elliptical copper cavity model has been started at PAVAC. The goal is to develop the fabrication process of bulk Nb multicell elliptical cavities.

CONCLUSIONS

Commissioning and operational results of ISAC-II demonstrate successful operation of 20MV (20 SC QWR) from 2006. The accelerator, upgraded in 2010, now consists of 40 SC QWR cavities with independent RF systems providing high flexibility for tuning. The design goal for ISAC-II to provide 40MV acceleration voltage is achieved.

Design, production and testing of SCRF cavities towards TTF/ILC elliptical bulk Nb cavities technology are ongoing at TRIUMF.

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