UPDATE ON SCRF DEVELOPMENT AT TRIUMF

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Abstract

Since 2007 TRIUMF started development of e-LINAC which is a 50 MeV 10 mA CW electron superconducting linear accelerator to be used as a driver to produce radioactive ion beams through photofission. The accelerator is based on five 1.3 GHz TTF/ILC elliptical bulk Nb cavities technology to be mounted in three cryomodules; an injector cryomodule with one cavity and two accelerating modules with two cavities each. The ISAC-II project superconducting heavy ion linear accelerator was successfully completed in 2010 and we now have in operation 40 superconducting bulk Nb QWR cavities assembled in eight cryomodules. Results and plans of the SCRF program and experience of ISAC-II operation at TRIUMF will be discussed.

INTRODUCTION

SCRF development at TRIUMF started with the ISAC-II project in 2000 [1]. In 2010 this project was completed with commissioning of a 40 MV superconducting linac for heavy ions. SCRF technology is now being used in a second `in house' linear accelerator, the e-LINAC, to produce 50 MeV electrons with intensities to 10 mA, which will be used as a photo-fission driver for the ARIEL rare isotope program at TRIUMF.

SCRF DEVELOPMENT FOR E-LINAC

E-LINAC [2] will consist of a 300 keV thermionic DC electron gun with RF modulated cathode grid and five elliptical 9-cell cavities, operating at 2^0K, in three cryomodules [3]. The layout and staging of the project are presented in Fig.1.

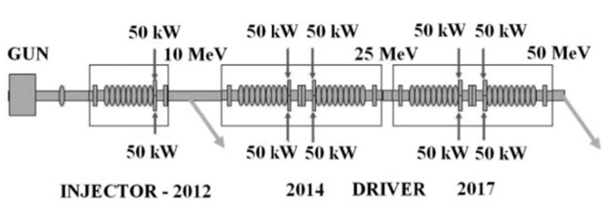

Figure 1: E-LINAC layout

Cavity Design

The e-LINAC cavity design draws from the 1.3 GHz elliptical TESLA-type cavity. Each cavity operates at an effective acceleration voltage of 10 MV with a design goal of Qo=1e10. Operating at 2^0K, the cavity dissipates 10 W in the liquid He system. Operation with 10 mA beam current requires 100 kW CW RF power into the cavity. To deliver RF power into the cavity two symmetrically opposed 65 kW CPI couplers are employed, providing the appropriate beam-loaded power while avoiding asymmetric coupler kicks. In result the e-LINAC 9-cell cavity differs from the TESLA cavity in the end cells, which are customized to adapt to the power couplers on the one end and also to mitigate HOMs and to flatten the field profile for the accelerating mode [4]. The main RF parameters of the cavity are very close to TESLA (Table 1). Simulations [5] show that multipacting occurs in the equatorial region of the cavity. Stable multipacting trajectories (over 40 RF periods) of order 2-4 were obtained in the range of 1.32 … 3.08 MV/m of the accelerating gradient and 1-2 order trajectories are obtained in a range of 3.08…17.16 MV/m.

Table 1: RF parameters of TRIUMF cavity in comparison with TESLA (DESY) cavity

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

HOM Dampers

HOM damper design concept is described in [4, 6]. A stainless steel damper ring is used for the coupler end while a CESIC ring is used for the opposite end. The rings are connected to a liquid Nitrogen heat sink. The conductivity of CESIC is measured by using the Q perturbation method in the elliptical cavity at 100^0K [7]. The result lies in the range 600…6200 S/m measured at 1.3 GHz and 660…3400 S/m at 2.4 GHz. The conductivity value is significantly below the rated value for CESIC, which is 15000 S/m.

ISBN 978-3-95450-125-0

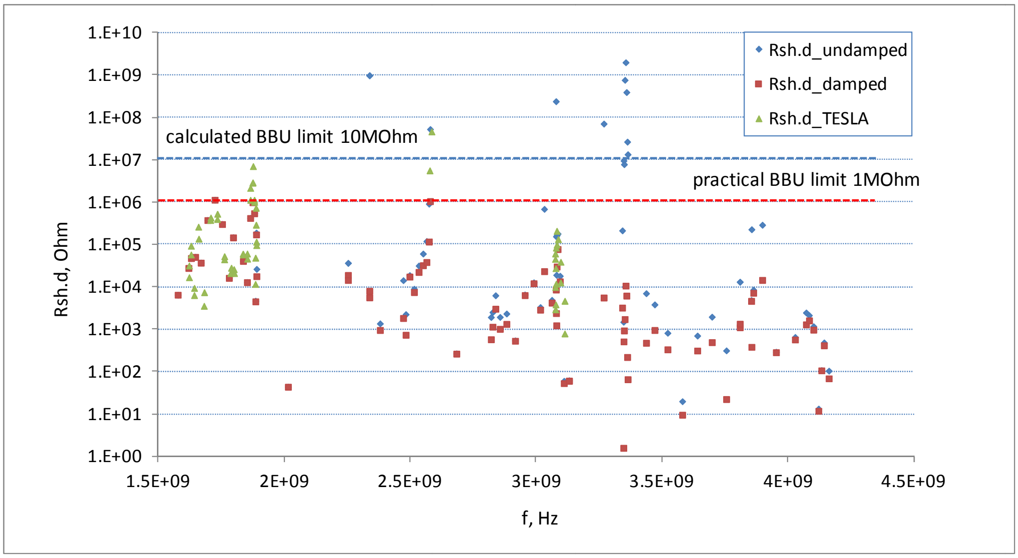

Figure 2: Spectrum of dipole HOM shunt impedances for TRIUMF cavity in comparison with TESLA nine-cell cavity

in the worst case the beam could be deflected by a dipole HOM with accompanying beam loss. This effect is called beam break up (BBU). It is dependent on the beam current as well as the shunt impedance, quality factor and resonant frequency of the dipole mode. The cavity has to be designed so that the shunt impedances and quality factors of the dipole modes do not restrict operation at 10 mA. Beam dynamic simulations result in a BBU criteria of Rsh.d < 10 MΩ. Expected fabrication tolerances result in a spread in $R_{sh.d}$ by a factor of ~2 [6]. Further contingency is gained by adopting a more restrictive criteria of $R_{sh,d}$ < 1 MΩ. Spectrums of $R_{sh.d}$ for HOM dipole modes for the e-LINAC nine-cell cavity with and without dampers together with the spectrum for TESLA cavity are presented on Fig. 2. Note that 1.72, 1.87 and 2.56 GHz modes (TE11) have marginal values of $R_{sh,d}$ compared to the practical BBU limit. The calculations assume the higher quoted value of CESIC conductivity while the measured data are below this value. In this way we could expect better damping at least for the 2.56 GHz mode.

Cavity Fabrication

Fabrication of the nine-cell TRIUMF cavity is on-going in collaboration with PAVAC Industries. A copper seven-cell mock-up of the cavity is completed (Fig.3). This cavity is now used for training on `field flattening' and for HOM studies.

The nine-cell niobium cavity design is shown in Fig.4 and utilizes a unique `smart bell' fabrication sequence with equator welds forming whole cells followed by iris welds to form multi-cells. A J-Lab style scissor tuner is employed and to avoid backlash the cavity is to be stretched by ~1 mm during operation. The nine-cell cavity fabrication now is underway with six `smart bells' fabricated meeting the correct frequency. Work is now starting on the end cells.

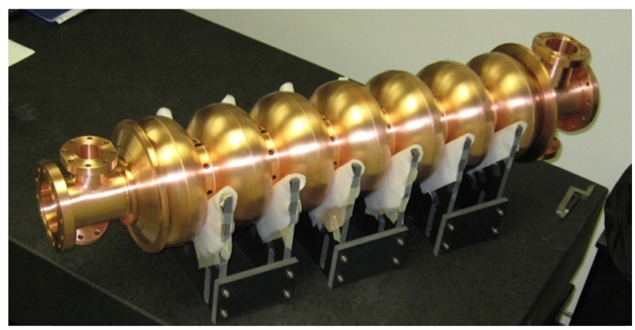

Figure 3: Seven-cell copper mock-up of the TRIUMF e-LINAC cavity

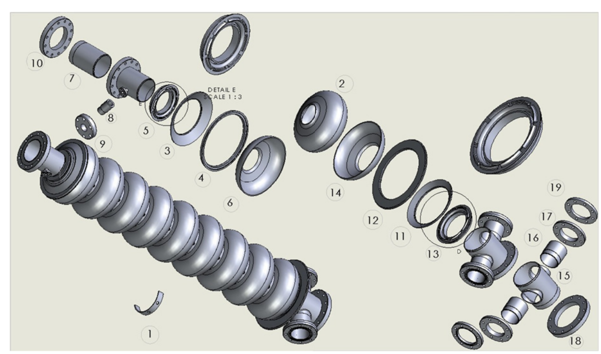

Figure 4: Mechanical design of e-LINAC nine-cell cavity

SCRF Cavity Testing

Single cell cavity tests are important to qualify cavity fabrication and Nb surface preparation processes. A series of preparation process improvements have been done:

- Degassing of PAVAC single cell cavity in a vacuum furnace at 800^{0}C (FNAL) to remove Hydrogen from the cavity surface.
- Completion of automatic HPWR unit to provide extended automatic rinsing.

ISBN 978-3-95450-125-0

- Cleaning pumping line to reduce contamination from active pumping during the cavity test.
- Improvement of clean assembly procedure protocol.
- Upgrade RF variable coupler and RF feedthroughs to allow RF multipacting and field emission conditioning without overheating the RF line.

Single cell cavity test results are presented in Fig. 5 with red dots after upgrades and brown squares before upgrades. Currently the cavity quality factor is $Q_0 \sim 10^{10}$ up to Ea=20 MV/m with a maximum gradient of 26 MV/m limited by local radiation levels. Green triangles on Fig.5 show the cavity Q-curve after improvements but employing a fast cavity cooldown. We believe that the cavity trapped magnetic flux due to thermal gradients (Seebeck effect) [8]. The `slow cooldown' result (red dots) is obtained after warming the cavity above 10K and re-cooling to reduce thermal gradients.

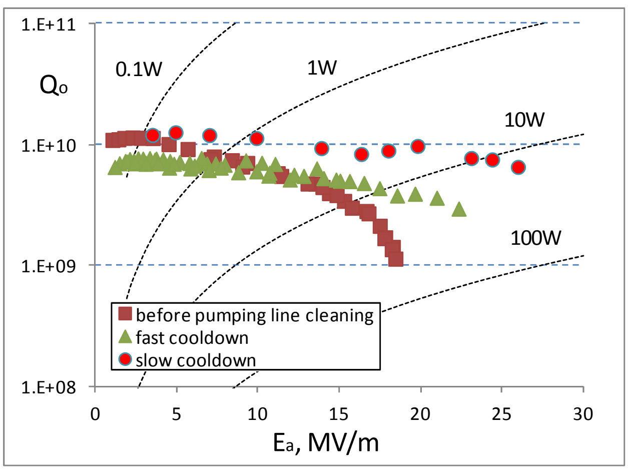

Figure 5: 1-cell cavity test results.

Plans for SCRF Development

For the nine-cell cavity test a vertical test cryostat is in fabrication. A variable transverse coupler is complete and second sound monitors to define quench location by sound wave triangulation are in development. A vacuum RF induction furnace is being developed to provide SC cavities degassing at 600…800^{0}C temperatures.

In addition further fundamental SRF material studies with the μ–SR and β–NMR TRIUMF facilities are in preparation [9].

ISAC-II SCRF DEVELOPMENT

Since the results for ISAC-II reported in [2] we have two years of successful operation. One identified problem is in the coupler line cables inside of the cryomodules with several failures due to RF breakdown in the cable isolation from RF glow discharge. Due to the flexibility of the accelerator structure consisting from many cavities with independent RF systems a failure can be easily compensated by means of increasing gradients and retuning other cavities. During planned shutdowns the damaged cables are replaced. To prevent this particular cable problem we restricted forward power levels in the RF amplifiers and initiated a cable test stand to develop a more robust cable.

Phase I of ISAC-II is using 1 kW tube-type RF power amplifiers, with a tube lifetime of ~12,000 hours. Two prototype solid state amplifiers at 600 W are now developed. Currently they are under test to take a decision about a replacement program.

CONCLUSIONS

In the end of 2012 we expect delivery from PAVAC of the e-LINAC nine-cell cavity and start SRF tests for cavity commissioning. Main resources are concentrated in this direction. Another important task for SRF development is to support the ISAC-II linac for reliable operation for users. TRIUMF is leveraging the installed infrastructure to support fundamental studies in SRF for student education and for implementation in current and future projects.

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ISBN 978-3-95450-125-0