PRODUCTION AND TESTING RESULTS OF SUPERCONDUCTING CAVITIES FOR ISAC-II HIGH BETA SECTION

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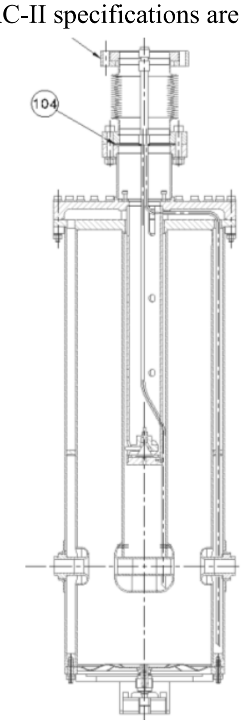
Abstract

The ISAC-II heavy ion linear accelerator has been in operation at TRIUMF since 2006. The high beta section of the accelerator, consisting of twenty cavities with optimum β_0=0.11, is currently under production and is scheduled for completion in 2009. The cavities are superconducting bulk Niobium two-gap quarter-wave resonators with a frequency of 141 MHz, providing, as a design goal, a voltage gain of V_{eff}=1.08 MV at 7 W power dissipation. Production of the cavities is with a Canadian company, PAVAC Industries of Richmond, B.C. after two prototype cavities were developed, produced and successfully tested. Cavity production details and test results will be presented and discussed.

INTRODUCTION

The high beta section will double the energy of the ISAC-II superconducting accelerator by means of an additional twenty cavities [1]. The plan is to install the completed and tested cryomodules in the end of 2009. Two cavity prototypes are successfully developed and tested in 2008 [2, 3]. Cavity design and parameters and ISAC-II specifications are presented on Fig.1.



Cavity Parameters

f	MHz	141.440
Aperture	mm	20
Gap	mm	35
Drift tube	mm	80
Outer diameter	mm	180
Inner diameter	mm	60
Height	mm	560
βo		0.112
TTFo		0.936
U/Ea^2	J/(MV/m)^2	0.067
RsQo	Ω	26
Ep/Ea		4.9
Bp/Ea	mT/(MV/m)	10
Sensitivity, Δf/Δx		
Beam ports	kHz/mm	120
Top plate	kHz/mm	-268
Bottom plate	kHz/mm	10

ISAC-II Specification

Pc	W	7
Veff	MV	1.08
Ea	MV/m	6
Ep	MV/m	29.4
Bp	mT	60

Figure 1: Cavity design and parameters.

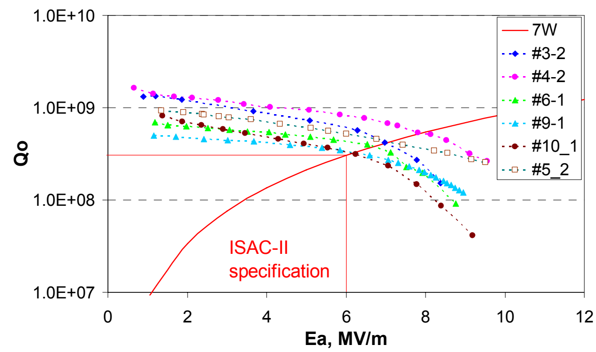


Figure 2: ISAC-II High Beta Section Cavities tests results.

CAVITY PRODUCTION

Cavity production started in the end of 2008 at PAVAC Industries with a planned delivery of three separate batches (6+6+8=20 cavities) corresponding to the number of cavities to be assembled in three cryomodules of the ISAC-II Phase II linac. To date six cavities have been delivered, processed and cold tested. Standard processing involves visual inspection, degreasing and a 60 µm BCP etch followed by one hour high pressure water rinse a 24 hour air dry and preparation for a cold test. The BCP etch of the cavities is now done in a new laboratory in the ISAC-II building with recirculating acid pumped through a Teflon heat exchange unit. The prototypes by comparison were done in a borrowed lab space at TRIUMF with cavity cooling done by forcing ice water through the cavity helium space during the etch. In a later section we will discuss the various aspects of the BCP etching process as pertaining to the expected cavity frequency swing. The first batch of six cavities was used for tuning of the production process. We made these cavities for first tests without final machining of bottom flange and with a mild BCP. Four cavities of the six met specification. Two cavities failed the leak test after the initial BCP and are now under repair. The leak in both cases is at the beam tube to inner conductor joint. The repair involves cutting out the inner conductor from the cavity at the upper niobium flange, repairing the leak and welding the inner conductor back into the flange using a supporting ring for back-fill. After initial characterization test each cavity receives a final machining of the bottom flange and a final BCP etch of ~40 µm.

Tuning Steps During Manufacture

According to our experience with prototype cavities the frequency shift between 300 and 4K (including thermal contraction, air-vacuum change and pressure change) is 264 kHz and this provides the target frequency for the manufacture. Cavity production consists of steps for parts machining, tuning and welding. The cavity tuning during the production is based on a cavity RF model and measurements for frequency sensitivities and prototype production experience for shrinks after welds. There are three main tuning steps:

- Cavity length adjustment before flanges welding; with a sensitivity of -268 kHz/mm (data on Fig.1)
- Acceleration gap adjustment before the beam ports welding; beam ports sensitivity 120 kHz/mm assuming movement at both gaps
- Final trim of bottom flange; with sensitivity ~10 kHz/mm

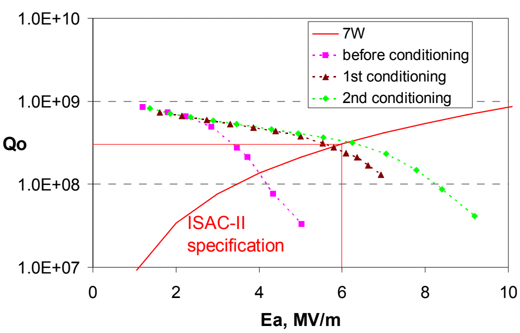


Figure 3: Cavity #10 RF conditioning.

Sensitivity Model and BCP

The first results from the new BCP chemical laboratory gave unpredictable resonant frequency shifts after initial etching. The problem was traced to a non uniform etching of the cavity due to:

- turbulent flow of acid inside of the cavity during the etching process
- "sludge" build-up – the Nb saturated acid drifts to the bottom of the cavity during etching and slows the removal rate at the root end. This is now mediated by removing the spent acid periodically from the cavity during etching

After some modifications to the etching process it is now found that we can use custom etching to fine tune the cavity frequency. This is accomplished by preferentially etching either the top half or the bottom of the cavity for a prescribed length of time followed by a full cavity etch.

According to analysis of the cavity with CST Microwave Studio an independent 1µm difference in etched layers for top or bottom halves corresponds to 2 kHz frequency shift. Enhanced etching at the beam port end of the cavity, for example, will increase the cavity frequency. The model is based on two halves cavity analysis with Slater frequency perturbation theorem; 1/4 of the cavity geometry was meshed with 2,000,000 cells.

The model was successfully applied for cavity tuning BCP etching.

TESTS

For cavity tests the TRIUMF ISAC-II single cavity cryostat was used and the results are presented on Fig. 2. The cavity is assembled and equipped with dissipator, coupler, tuning plate, pickup, temperature sensors and enclosed in mu-metal shield. The cavity is pumped then baked for two days achieving a temperature of 360K at a vacuum of 10^{-6}Torr. This is followed by two days of radiative cooling with LN2 in the thermal shields to reach 200K before filling the cryostat with liquid helium. The resonant frequency of the superconducting cavities is within +/-17 kHz of the goal operational frequency 141.44 MHz within the range of compensation allowed by small deformations of the tuning plate.

Cavity test procedure consists of

- Multipactoring conditioning during cooldown and at helium temperature
- RF power measurement calibration. The calibration was verified with equivalent cavity bath heater and an He flow meter
- Pickup calibration with decay time measurement for critically coupled cavity
- Q-curve reference measurement
- RF pulsing conditioning
- He pressure sensitivity measurement by measuring the frequency change during He pressure variations

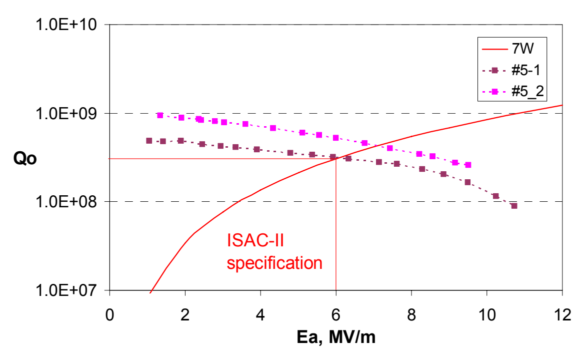


Figure 4: Cavity #5 after 1st (#5_1) and 2nd (#5_2) BCP.

Multipactoring

Measurements and 3D multipactoring simulations in MultP-M code [4] for this cavity show that the levels are quite below operational field levels and don't affect the cavity operational parameters. Rather they just hamper cavity turn-on. Table 1 shows the results of multipactoring simulations and measurements. The conditioning at room temperature and at temperatures above 200K during cavity cooldown in driven mode in CW helps to clean the cavity from multipactoring up to 100 kV/m. Multipactoring levels are reappearing again at helium temperature but they are weak though sometimes create problems for power-on. A few minutes of pulse conditioning in self-excited overcoupled mode effectively cleans the cavity.

Table 1: Multipactor Levels of the Cavity

Simulation by MultP-M code		Measured
E_a, kV/m	Cavity region	E_a, kV/m
12.0 – 26.0	accelerating gap, donut – coax outer conductor	10 – 24
27.0 – 33.0	donut – coax outer conductor	28 – 33
35.0 – 54.0	coax line donut – end cap	42 – 50
58.0 – 193.0	donut – end cap	77 – 80

RF Conditioning

After multipactor conditioning and pickup calibration we take an initial Q-curve for reference. This is followed by RF conditioning to improve cavity performance. To avoid strong radiation we are using RF pulses ~0.1s with period ~1 s for an overcoupled cavity with forward power ~200W during ~ 0.5-1hour. To increase the efficiency of RF conditioning we also leak He gas to the cavity vacuum to ~10^{-5}Torr. This helps to achieve better operational parameters. As an example Fig.3 shows a Q-curve before and after RF conditioning. The Q-curve before conditioning was limited by X-ray radiation followed by a quench. In the result the acceleration gradient at nominal cryogenic power 7W increased from 4 to 5.8 and then to 6.2 MV/m. The maximum acceleration gradient before quench was increased from 5 to 7 and then to 9.2 MV/m.

Test Results

The test results for four production cavities (#5, 6, 9 and 10) are presented on Fig. 2 together with prototype tests results (#3 and 4). Index _1 in the test result legend means the test after the 1st BCP and _2 – the test after final bottom flange machining and 2nd BCP. All cavities, even before final machining and BCP, meet ISAC-II specification (Ea=6 MV/m, Ep=30MV/m and V_{eff}=1.08 MV at 7W). Cavity #5_2 result is above ISAC-II specification and close to prototype results. Fig. 4 shows cavity#5 tests results after 1st (#5_1) and 2nd (#5_2) BCP. The deeper BCP process and better fitting of tuning plate to the cavity flange leads to a Qo increase of almost 2 times, from $5*10^8$ to $9.4*10^8$. It corresponds to a decrease in the surface resistance from 52 to 28 nΩ. Most importantly there is an increase of acceleration gradient at nominal 7 W power dissipation from 6 to 7 MV/m. The 2nd BCP for cavities #6, 9 and 10, and final flange machining have now been done and we expect improved results in next tests from experience with cavity #5.

He pressure sensitivity for the production cavities is ~-1 Hz/Torr which is ~3 time less than for prototype due to better stiffening at cavity assembly.

Lorentz force detuning measured at these tests was ~-1 Hz/(MV/m)^2 which is the same as for prototypes.

CONCLUSIONS

Production of the 20 High Beta Cavities for ISAC-II High Beta Section is going full speed at PAVAC. The first six cavities are produced, tested and installed in the first cryomodule.

The tested cavities meet and even exceed ISAC-II specification (Ea=6 MV/m, Ep=30MV/m and V_{eff}=1.08 MV at 7W power dissipation).

The new BCP chemical laboratory was setup at TRIUMF. The BCP process was studied and tuned. A sensitivity model of the cavity was successfully used for tuning of the cavity frequency with BCP.

Measurements and 3D simulations of multipactoring in the cavity show low levels of multipactoring, significantly less than the operational field. These low levels just hamper sometimes power-on of the cavity. The multipactoring conditioning procedure is developed and doesn't take much time.

In the end of May 2009 we expect the next six cavities and last eight cavities in the middle of August 2009.

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