PRODUCTION AND TESTING OF TWO 141 MHz PROTOTYPE QUARTER WAVE CAVITIES FOR ISAC-II

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Abstract

The medium beta section of the ISAC-II superconducting linac (β=5.7% and 7.1%) has been operational since April 2006 providing 20 MV of accelerating potential at 106 MHz. The 'high beta' extension to the linac, in progress, will see the addition of twenty 141 MHz quarter wave cavities at $\beta = 11\%$. The design specification calls for cw operation at a voltage gain of at least 1.1 MV/cavity for no more than 7 W of power dissipated in the cavity. This operation point corresponds to challenging peak surface fields of 30 MV/m and 60 mT. The cavity design is similar in concept to the medium beta cavities except for the addition of a drift tube to render symmetric the accelerating fields. A prototyping and qualification program was initiated with PAVAC Industries Inc. of Richmond, B.C. Two full size models in copper and two in niobium have been completed. The cold performance of both cavities exceeds the specification and the final frequency is within tuning range. The design, fabrication details and test results will be presented.

INTRODUCTION

The high beta section will double the voltage gain of the ISAC-II superconducting accelerator by means of an additional twenty cavities[1]. These cavities will be housed in three cryomodules with common isolation and cavity vacuum. Two cryomodules will contain six cavities and the last one will contain eight cavities. The plan is to install the completed and tested cryomodules during an extended shutdown of ISAC-II starting in September 2009. The medium beta section is in operation since April 2006 and is reliably operating at an average acceleration gradient of 7 MV/m at 7 W cavity power, corresponding to peak electric and magnetic fields of 35 MV/m and 70 mT[2] and represent the highest values for an operating cw heavy ion linac. The medium beta design was accepted as a basis for the design of the high beta section.

CAVITY DESIGN

The design of the new ISAC-II superconducting high beta cavity is presented in Fig. 1 and it is similar in structure to the medium beta 106 MHz cavities design[3]. The operational frequency is 141.44 MHz and $\beta_0 = 0.11$. It is a bulk niobium double wall structure ~25% shorter than the medium beta cavity. The main difference is the donut shaped inner drift tube to provide higher geometric β and transit time factor (TTF), and improved field symmetry. The acceleration gap is reduced from 40 to 35 mm and the grounded beam ports diameter is also reduced from 60 to 50 mm to achieve a 115 mm gap to gap distance with the 180/60 mm coaxial arrangement. The position of RF ports was optimized for coupler operation. A mechanical dissipator is inserted inside of the inner conductor of the cavity to dampen vibrations. The bottom plate of the cavity is modulated and slotted to provide a deformation of at least 3 mm for cavity tuning.

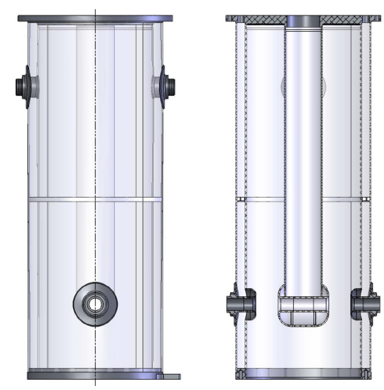

Figure 1: ISAC-II high beta cavity design.

CST 2008 Microwave Studio model and cavity parameters are shown in Fig.2. Virtual volumes in the model were used in the simulation to avoid errors from meshing. The models include a virtual cylinder around the beam tube donut and a virtual coaxial in the high magnetic field stem region. The peak electric field, E_p, is calculated from a donut geometry parameterization. B_p is calculated assuming a cosine longitudinal, hyperbolic radial magnetic field distribution in the virtual coaxial and the value of magnetic field stored in this volume. Frequency sensitivity for beam ports and top and bottom flange displacements are calculated from surface densities of electric and magnetic fields by using the Slater theorem. The acceleration gradient definition is $E_a = V_a/D$ where V_a is an acceleration voltage gain of the cavity at optimum velocity β_0 (including a transit time factor TTF_0), D is a conventional cavity length chosen as the cavity outer conductor diameter. The design goal is $E_a = 6$ MV/m and corresponds to $V_a = 1.08$ MV. The steering effect due to the electric and magnetic transverse rf fields can be largely compen-

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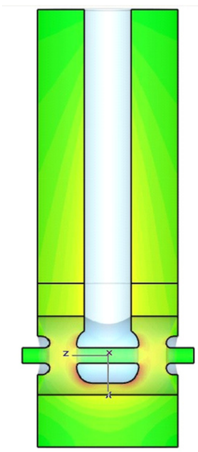
sated by shifting the cavity 1.3 mm downward relatively to the optical axis. The bottom tuning plate is removeable for easy cavity access with a metal to metal contact. The tuning plate position is optimized to have sufficient frequency sensitivity, ∼8 Hz/mm, while maintaining an acceptably low magnetic field ratio $B_c/E_a < 0.1$ mT/(MV/m) in the bottom tuning plate to flange non-welded contact.



f	MHz	141.44
aperture	mm	20
gap	mm	35
drift	mm	80
Outer dia	mm	180
Inner dia	mm	60
Height	mm	560
bo		0.112
TTFo		0.936
U/Ea^2	J/(MV/m)^2	0.067
RsQo	Ohm	26
Ep/Ea		4.9
Bp/Ea	mT/(MV/m)	10
Bc/Ea	mT/(MV/m)	0.1
Df/Dx	kHz/mm	
beam ports		120
top		-268
bottom		8

Figure 2: CST model and cavity RF parameters.

PRODUCTION

Initially two copper dummy cavities were produced at PAVAC Industries. This modelling period was useful in developing forming and welding fixtures and to develop frequency tuning steps and helped streamline the Nb production. Forming fixtures for rolling the inner and outer conductor were developed to roll and shape the 2mm Nb sheet. The donut beam tube was formed in three steps. The beam tube and end caps were machined from solid bar then welded into a sub-assembly. An outer shroud made from 1mm material was then rolled, machined and welded to the sub-assembly before final machining and welding to the inner conductor.

Frequency goals and tuning procedures during production were defined based on the data from the copper dummy cavities production, frequency sensitivities from CST cavity model and niobium welding trials. The sequence of tuning operations for the cavity production is the following:

- The inner and outer conductor length are trimmed before flanges welding with a sensitivity of -268 kHz/mm (data in Fig. 2).

- The acceleration gap adjustment is done by first determining the correct after weld gaps from rf frequency measurement then fixing the gaps with a welding jig with dimensions to compensate for the expected weld distortion. The beam ports sensitivity is 60 kHz/mm for total shift from both gaps.

- There is a final machining of the bottom flange after the initial cold test to set the final frequency; sensitivity is ∼8 kHz/mm.

BCP etching of parts prior to welding was done at TRIUMF with the standard 1:1:2 BCP with a typical etch rate of 1μm/minute. After all welds, tunings and pressure tests the cavities were BCP etched $\sim 80\mu$m and high pressure rinsed with deionised water.

CAVITY TESTS

Cavity tests were performed in the ISAC-II single cavity cryostat. The cavity is assembled and equipped with dissipator, coupler, tuning plate, pickup, temperature sensors and enclosed in mu-metal shield. After cavity pumping the frequency shift of +42 kHz corresponds to the air-vacuum shift (air dielectric constant=1.0005855) only and not due to alterations in the cavity volume. The cavity is pumped then baked for two days to achieve a temperature of 360°K at a vacuum of 1e-6 Torr. This is followed by two days of radiative cooling with LN2 in the thermal shields to reach 200°K before filling the cryostat with liquid helium. The estimate of frequency shift from room temperature to cold temperature was done based on previous experience with the medium beta ISAC-II cavities and Alpi cavities of INFN-LNL. To a good approximation the frequency shift is proportional to operational frequency. Following this scaling we predicted a 253 kHz frequency shift. This is just 4.5% less than the actual shift of 264 kHz. 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.

Table 1: Prototype cavities test results.

Parameter	Prototype 1	Prototype 2
f_o (MHz)	141.423	141.456
Q_0	1.10e09	1.20e09
E_a (MV/m) @ 7 W	8.1	8.8
E_p (MV/m) @ 7 W	40	43
B_p (mT) @ 7 W	81	88
$E_a$max (MV/m)	10.9	12.5
$E_p$max (MV/m)	53	61
$B_p$max (mT)	109	125
df/dP (Hz/Torr)	3.3	1.7
$df/d(E_a)^2$ (Hz/(MV/m)^2)	-0.8	-0.9
Δf (kHz) (300K-4K)	263	265

RF conditioning of the cavity indicated the 1st level of multipacting at $E_a \sim 10$ kV/m, which according to Frequency-Gap Product in the Two Surface Multipactor model[4], corresponds to the 1st order of the acceleration gaps. There are also several higher levels. The multipactor levels process out in several hours using pulsed rf conditioning at strong coupling. Both prototypes exhibited strong field emission at ∼5 MV/m that could be eventually conditioned out by repeated conditioning. RF conditioning pulses varied from ΔT∼0.2-0.5 s and T∼1 s at a forward power of 200-400 W with overcoupling to achieve fast cavity response with sufficient field level. Helium conditioning at ∼1e-5 Torr was also employed. The calibration of the pickup voltage for acceleration gradient E_a is calculated from the decay time constant and power dissipation during critically coupled cavity measurements.

The resulting Q-curves after conditioning of the prototype cavity cold tests are presented in Fig. 3 and the test summary data are presented in Table 1. A maximum cw acceleration gradient for one prototype of $E_a > 12$ MV/m is achieved, which corresponds to $E_p > 60$ MV/m and $B_p > 120$ mT. The limitation is from radiation levels produced in the test area. At 7 W power dissipation the cavities acceleration field $E_a = 8.5$ MV/m significantly exceeds the design goal of 6 MV/m. The measured quality factor $Q_0 = 1.2\text{e}9$ corresponds to a residual resistance of ∼15 nΩ.

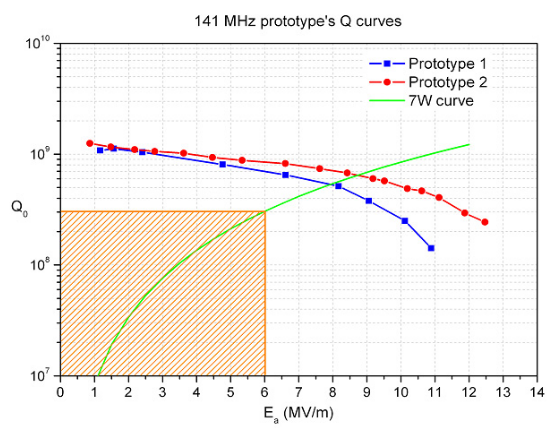


Figure 3: RF characterization results for prototype cavities.

A Q-disease test has been done for one of the cavities. The cavity was kept in the range 50-150 K for several days due to a cryogenic problem. The Q-curve taken after this is shown in Fig. 4. The quality factor drops an order of magnitude and the Q-curve shape becomes concave upward, a characteristic of Q-disease. After thermal cycling up to room temperature the Q-disease disappears.

The cavity lowest mechanical resonance frequency ∼110 Hz is calculated and measured. Vibration measurements are taken with and without a mechanical dissipater in position. The peak phase error signal after a calibrated cavity excitation for the two cases is shown in Fig. 5. The dissipator helps reduce the forward power (reduce the over-coupling) required to provide a stable bandwidth for cavity operation.

SUMMARY

Two superconducting bulk niobium ISAC-II high beta prototype cavities have been developed, produced and successfully tested. The acceleration gradient at nominal power dissipation 7 W is 8.5 MV/m corresponding to a

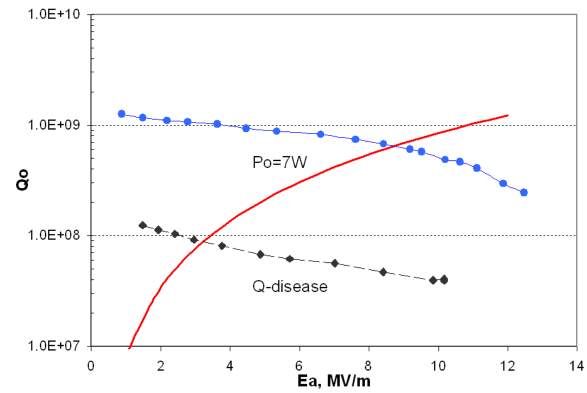


Figure 4: Prototype 2 with and without Q-disease.

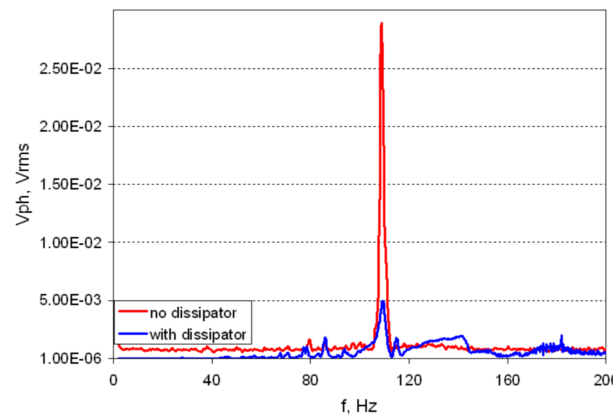


Figure 5: Phase noise with and without dissipator.

peak surface field in excess of 40 MV/m. The fabrication of twenty cavities are underway at PAVAC with the first six expected in October 2008. The Phase II extension is expected to be completed in Dec. 2009.

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