RF CAVITY PERFORMANCE FOR THE ISAC-II SUPERCONDUCTING LINAC

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Abstract

The ISAC-II superconducting linac with twenty 106 MHz quarter wave cavities is now operational since April 2006. The cryomodule design is such that the cavity rf surfaces share the vacuum space with the thermal isolation volume. Because of this we are interested in logging the performance of the cavities over time to estimate degradation due to contamination during operation or maintenance. Early commissioning demonstrated on-line cw performance at a peak surface field in excess of 35 MV/m. Performance after one year of operation and a full thermal cycle during the annual shutdown shows very little degradation in performance. The paper summarizes the rf performance with a particular look at maintenance and operation issues.

INTRODUCTION

TRIUMF has installed a new heavy ion superconducting linac as an extension to the ISAC facility [1], to add ~ 20 MV of accelerating voltage to the existing room temperature linac capability of 1.5 MeV/u for ions with $A/q \leq 6$. The superconducting linac is composed of twenty bulk niobium, quarter wave, rf cavities, for acceleration, and superconducting solenoids, for periodic transverse focussing, housed in five cryomodules. The first eight have a design velocity of $\beta_o = 5.7$ % while the remaining twelve have a design velocity of $\beta_o = 7.1$ % (Fig. 1). The design goal for the ISAC-II medium beta cavities (see Fig. 1) is to operate up to 6 MV/m across an 18 cm effective length with $P_{cav} \leq 7$ W. The ISAC-II design gradient corresponds to an acceleration voltage of 1.1 MV, a peak surface field of $E_p = 30$ MV/m and a stored energy of $U_o = 3.2$ J. The high peak surface field demands clean rf surfaces.

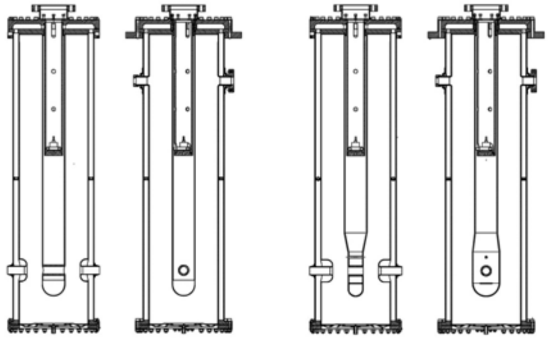
(a) Nominal (β=7.1%) (b) Flat (β=5.7%)

Figure 1: The two medium beta quarter wave cavities for the ISAC-II linac.

The electron beam community has adopted cryomodules designed to isolate the beam/rf space from the vacuum space that surrounds the cavity and acts as the thermal shield. In that case the elliptical cavities are an extension of the beam pipe and the rf volume is pumped through the beam ports. The cavities can be assembled in the cleam room as single units or in a string, valved off and moved to a cryomodule assembly station. The assembly of the cryomodule does not have to be done in a clean room since the rf surfaces are isolated and the choice of materials and insulating techniques are not limited by concerns on particulate formation or volatiles. For instance the use of multi layer insulation is not precluded but is readily used. In contrast superconducting heavy ion linacs have historically used a single vacuum space in the cryomodules. The cavities, typically quarter waves have a large internal surface area in relation to the beam gap due to the low frequency, low beta application. The beam dynamics requires a close packing factor of cavities and transverse focussing elements so the engineering of the cavity vacuum couplings is challenging. In the case of the ISAC-II linac it was decided that, for simplicity of mechanical assembly, a single vacuum space for cavity and thermal isolation is used but clean assembly methods and cavity rinsing are adopted. Noteworthy is the fact that many of the present heavy ion initiatives in the last few years, namely RIA, SOREQ and SPIRAL-II, are being designed with separate vacuum systems for the thermal vacuum and the beam/rf vacuum.

Cryomodules

Each module has two main assemblies, the top assembly and the tank assembly[2]. The top assembly shown in Fig. 2 and Fig. 3 includes the vacuum tank lid, the lid mu-metal and LN2 shield, the cold mass and the cold mass support.

The tank consists of the vacuum tank, the mu-metal liner and the LN2 box insert. Both the top and bottom subcomponents are assembled separately in a ‘dirty assembly’ area as a pre-assembly step. The sub-components are then disassembled, cleaned and delivered to the ISAC-II clean room for final assembly, alignment and testing.

Each cryomodule has a single vacuum system for thermo-isolation and beam. All components are cleaned in an ultrasound tank and air-dried in the clean room. No volatile lubricants or flux are used during the assembly. Particulate generators such as multi-layer insulation are also strictly avoided.

Installation of the linac was also controlled since the

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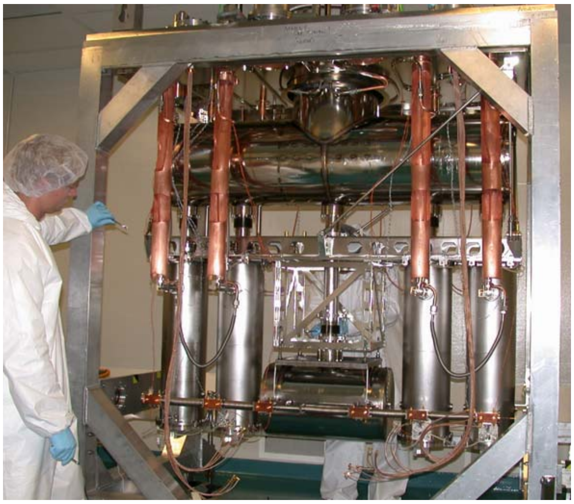

Figure 2: Cryomodule top assembly in the assembly frame prior to the cold test.

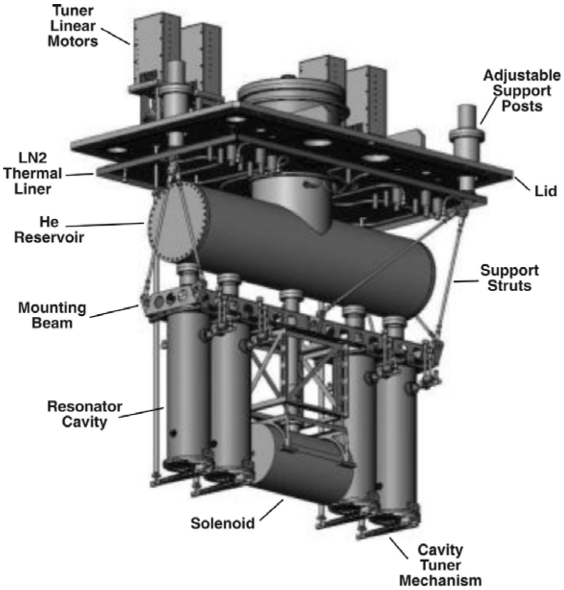

Figure 3: The cryomodule top assembly.

vault environment is not ‘clean’. Any opening of the vacuum space to the environment is accompanied by a slight overpressure with filtered nitrogen to reduce the back migration of particulates into the chamber. Any venting of the cryomodules and subsequent pumping is done slowly (5 Torr per minute) to reduce the risk of drawing airborn particulate into the cavities. Each cryomodule comes equiped with an upstream and downstream isolation valve. The beamline vacuum sections upstream and downstream of the linac are pre-cleaned and during operation are treated as extensions of the cryomodule. That is they follow the same protocol for venting and opening as is done for the cryomodules. The beamline is equiped with cold traps upstream and downstream of the linac to trap volatiles that might migrate to the rf surface. All pumps in the cryomodule and beamlines of ISAC-II are backed with oil free scroll pumps.

LINAC OPERATION AND COMMISSIONING

First beam from the linac came in April 2006 followed by a full set of commissioning studies. The first radioactive beam was accelerated in January 2007 followed by a shutdown with a full warm-up and maintenance activities. Beam production was resumed in May 2007.

The average cavity gradients for each cavity for three different beam accelerations as calculated from the acceleration rate are shown in Fig. 4. The average gradient in each case is 7.2 MV/m corresponding to an average peak surface field of 36 MV/m and an average voltage gain of 1.3 MV/cavity.

Initial rf test results from the single cavity cryostat are plotted for comparison[4]. In this case the average peak surface field for the cavities is 38 MV/m at a cavity power of 7 W. This corresponds to a gradient of 7.6 MV/m and a voltage gain per cavity of 1.4 MV. The *in situ* gradients in general match well the gradients from initial single cavity tests. A few cavities have obviously been contaminated during assembly, pump-down or cooldown, namely 8, 12, 14 and 20. Of these three appear in the downstream location in the module and so may be victem to a systematic contamination. Others, 1 and 19, have improved perhaps during the final assembly rinse or through repeated conditioning. A significant point is that the average operating gradient during the initial commissioning period is down by only 5% from the single cavity result.

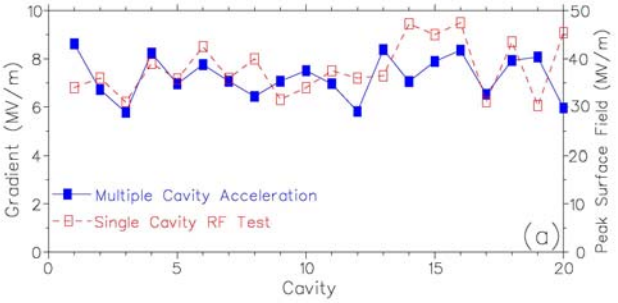

Figure 4: (a) Average cavity gradients during the initial acceleration for 7 W of cavity power. Results are inferred from the step energy gain per cavity during acceleration. Also shown are gradients from initial single cavity characterizations.

Shutdown Activities and Start-up

RIB production at the ISAC facility is dependent on the availability of the TRIUMF cyclotron drive beam. The cyclotron typically is shut down for three months of the year and the ISAC-II linac is warmed during these shutdown periods. During the shutdown significant work was done.

One cryomodule (CM1) was taken out of the line, removed to the cleanroom and the cold mass opened for repair of a coupling loop drive. The removal, repair and reinstallation of the cryomodule takes about two weeks.

As well four turbo-pumps, two Leybold Maglevs (CM1, CM2) and two Varian pumps with ceramic bearings (CM3, CM4) had failed during the previous running period. (The reason for the high rate of failure (four out of ten) is still not clear.) One of the pumps (CM1) was replaced in the clean room during the coupling loop drive repair. The other three were replaced *in situ*. A plan was established to replace the turbos to minimize particulate contamination. The replacements were done by venting slowly with filtered nitrogen and removing the pump while providing a slight overpressure of filtered nitrogen. The replacement turbo was pre-cleaned in the clean room, bagged and standing by for quick replacement. During repair it was discovered that one Varian pump on CM4 had completely failed with turbine blade shards scattered on the LN2 thermal liner (see Fig. 5.) The shards were removed from the turbo-pump port, the LN2 shield vacuumed as access would allow and the pump was replaced. No attempt was made to remove the cryomodule for particulate decontamination in the clean room due to the lack of time.

Figure 5: The remains of a turbo pump after touch down failure in cryomodule CM4.

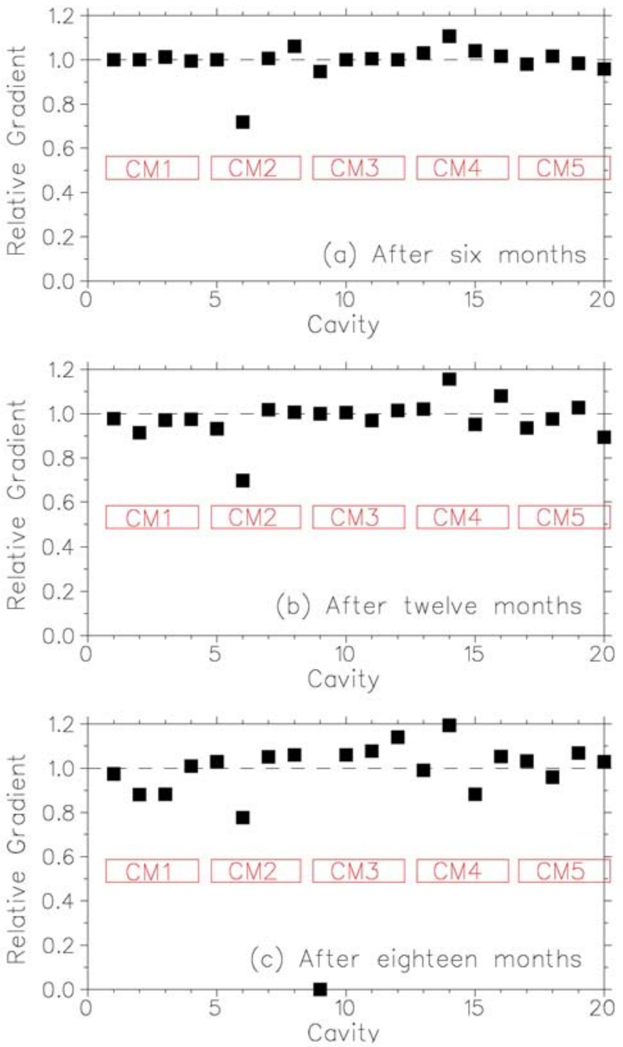

Figure 6: A comparison of the relative 7 W cavity gradients after the initial operating period (six months), after the shutdown (twelve months) and after the second running period (eighteen months) compared to the gradients recorded in initial measurements.

These activities proved a good test of procedures and give some indication of the sensitivity of cavity performance to contamination and to warming cycles. A comparison of the relative 7 W cavity gradients after the initial operating period (six months), after the shutdown (twelve months) and after the second running period (eighteen months) compared to the gradients recorded in initial measurements are shown in Fig. 6.

The cavity performance records show no degradation, within the accuracy of the measurements, with an average of 99% of performance after six months, 98% after twelve months and 100% after eighteen months. Not included in the gradient statistics is CM3:Cav1 which had an in vacuum failure of the rf drive during the last running period. It is interesting to note that the statistical variation in the cavity performance seems to be increasing over time but the average performance remains the same. In particular despite the work done in the shutdown the cavity performance in CM1 and CM4 were unaffected. The one significant change is to CM2:Cavity2 that has suffered a modest performance reduction that we think is related to Q disease.

On two occasion cryogenic procedures forced a warm-up of the cavities above transition. Since the solenoids have a larger thermal mass they stayed below transition and even though driven to zero still retained frozen flux that upon subsequent cooldown contaminated the adjacent cavities and reduced the Q. This is a well documented phenomenon [3] observed during cryomodule testing. The solution is to warm both the solenoid and cavities above transition to quench the frozen flux before recooling. After this procedure cavity performance returned to previous levels.

CONCLUSION

The performance represents the highest accelerating gradient for any operating cw heavy ion linac. The experience from the year and a half of operation including full thermal cycling and significant maintenance and repair involving venting of the primary vacuum of sixteen of the cavities indicates stable cavity performance with little or no cavity degradation. This is extremely encouraging and suggests that for cw applications a single vacuum system does not preclude high performance operation.

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