ISAC-II QWR Cavity Characterizations and Investigations

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Abstract

A heavy ion superconducting linac is being installed at ISAC/TRIUMF. A first stage of the ISAC-II upgrade at TRIUMF will see the installation of 20 quarter wave bulk niobium cavities (Beta0=0.057,0.071). The cavities operate cw at 106 MHz with design peak fields of Ep=30 MV/m, Bp=60 mT while delivering an accelerating voltage of 1.08 MV at ∼4 W power consumption. All of the cavities have received BCP processing with two of the cavities receiving an additional electro-polishing treatment. The cavities have been fully characterized for rf performance and are presently being mounted in cryomodules for an initial beam test in Dec. 2005. The report will summarize the cavity treatment procedures and present the cavity test results. In particular we compare the EP vs. BCP treatment and present data confirming the presence of Q-disease in the BCP cavities.

INTRODUCTION

A first stage of the new heavy ion linac at TRIUMF will see the installation of twenty 106 MHz bulk niobium quarter wave cavities. The cavities, originally developed at INFN-LNL[1] and fabricated at Zanon in Italy, are two-gap bulk niobium quarter wave cavities. Eight of the cavities have a design beta of 5.7% with the remaining twelve having a design beta of 7.1% (Fig. 1). The ISAC-II medium beta cavity design goal is to operate up to 6 MV/m across an 18 cm effective length with $P_{\rm cav} \leq 7$ W. The gradient corresponds to an acceleration voltage of 1.1 MV, a challenging peak surface field of $E_p = 30$ MV/m,, a peak magnetic field of 60 mT and a stored energy of $U_o = 3.2$ J and is a significant increase over other operating heavy ion facilities.

RF ANCILLARIES

The cavities are equipped with a mechanical damper which limits microphonics to less than a few Hz rms. A demountable flange on the high field end supports the tuning plate. Rf coupling is done through a side port To achieve stable phase and amplitude control the cavity natural bandwidth of ±0.1 Hz is broadened by overcoupling to accommodate detuning by microphonic noise and helium pressure fluctuation. The chosen tuning bandwidth of ±20 Hz demands a cw forward power of ∼200 W ($\beta \simeq 200$) and peak power capability of ∼400 W to be delivered to the coupling loop. A new coupler has been developed[2] that reduces the helium load to less than 0.5 W at $P_f = 200$ W. The tuning plate on the bottom of the cavity is actuated by a vertically mounted permanent magnet linear servo motor at the top of the cryostat using a 'zero backlash' lever and push rod configuration through a bellows feedthrough[3]. The system resolution at the tuner plate center is $\sim 0.055\mu$m (0.3 Hz).

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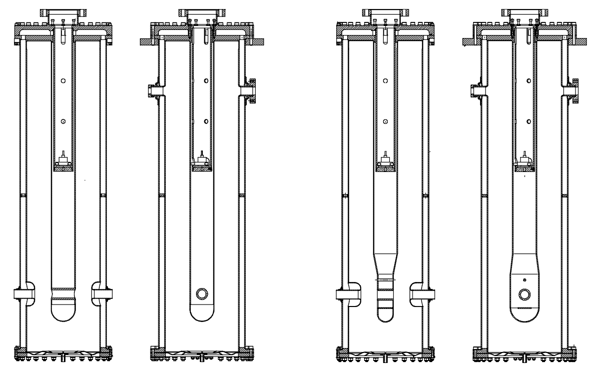

Figure 1: The two medium beta quarter wave cavities for the ISAC-II linac.

CAVITY TESTING

The cavities were fabricated at Zanon in Italy. The initial four were chemically polished at CERN and the remaining sixteen were chemically polished at JLab. Recently two cavities received additional electro-polishing in a collaboration with Argonne. To date nineteen cavities have been characterized via cold test. Cold tests are done in the SCRF Clean Room facility in the new ISAC-II building. A single cavity cryostat with LN2 thermal shield is used for all the cavity characterization studies. Typical treatment involves a 30-40 minute high pressure water rinse and twenty four hour air dry in a clean room, followed by vacuum pumping and bakeout at 95C for 48 hours. The cavities are then pre-cooled for 48 hours before helium transfer.

All initial tests involved a pre-cool with LN2. A small flow of LN2 was delivered to the inner conductor volume and maintained until the outer metal sensors indicated $\sim$ 170K. Radiation and thermalization would bring the cavity to 160K before helium transfer. Recently we have found that this procedure is responsible for a degradation in performance from Q-disease. A fast cool-down procedure is now used where the cavity is radiation cooled to $\sim$ 220K for 48 hours and then rapidly cooled with LHe down below 50K in less than one hour. The LHe flow is $\sim$ 50 ltr/hr.

Q-Disease

A distribution of the initial cavity performance for seventeen cavities is shown in the top plot of Fig. 2. The performance is characterized by the peak surface field for 7 W cavity power. Four cavities out of the seventeen did not meet specification with at least one cavity being very poor.

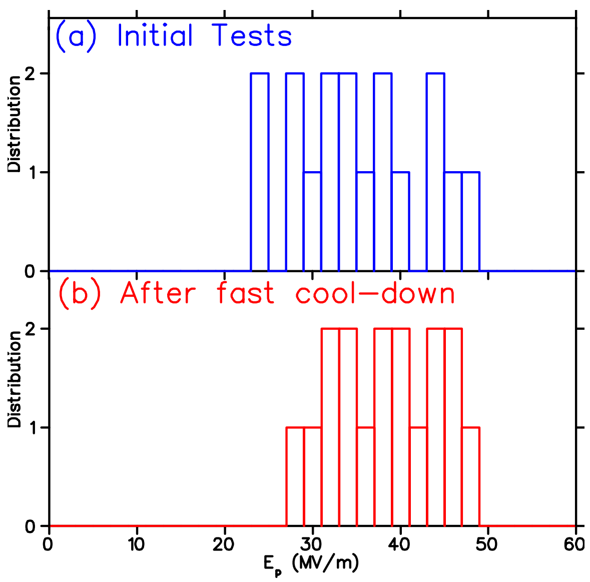

Figure 2: Histogram summarizing cavity performance for seventeen tested cavities. Shown are the numbers of cavities achieving a certain peak surface field at 7W helium load. Initial tests are shown in the top plot and recent status is shown in the bottom plot after testing poorer cavities with a fast cooldown.

An initial suspicion of Q-disease developed after a cavity electro-polished at Argonne (cavity 11) showed a poor performance (see below). This test was followed by a test on a BCP only cavity (cavity 17) also with poor performance and with a characterization curve that resembled the curve for the E-P cavity. The characterization curve showed a steep Q-slope at low field followed by a reduction in slope towards higher field. Fig. 3 summarizes the results of tests with Cavity 17. The original test did not meet ISAC-II specifications. The cavity was warmed to 110K for 18 hours before retesting this time with a marked reduction in Q_o typical of hydride formation. Finally Cavity 17 was retested with no LN2 pre-cool with Q_o rising from 0.8×10^9 to 2×10^9.

The result led to a reevaluation of the testing procedure. During the initial cavity cooldown with LN2 care is taken to avoid cooling the sensors on the cavity flanges to less than 160 K. However a sensor in the inner conductor helium space does reach LN2 temperatures for extended periods. A study was undertaken to correlate cavity performance to the temperature of this sensor in the inner conductor. Fig. 4 summarizes the results. It is clear that when the inner conductor sensor remains at temperatures between 80K to 150K for periods exceeding 15 hours a degradation

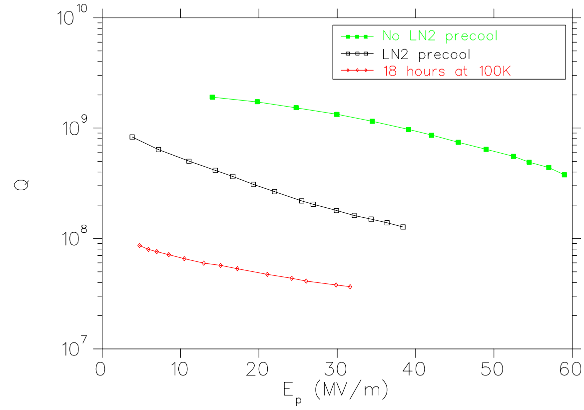

Figure 3: Summary of test results for cavity 17.

in the cavity Q can occur.

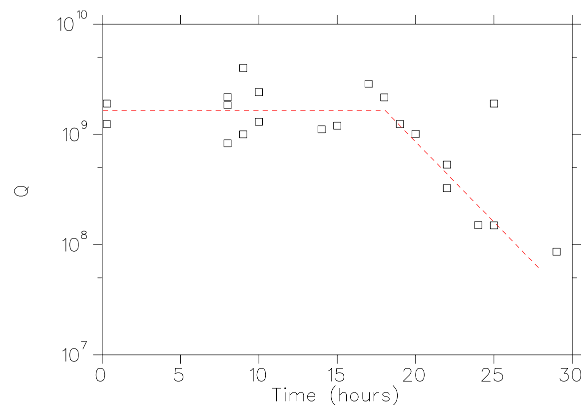

Figure 4: Cavity Q as a function of time that temperature sensor TS1, a bath sensor inside inner conductor, is between 80 and 150K.

Since this discovery several cavities that originally had poor performances were retested. The results for cavities 9 and 12 are shown in Fig. 5 and Fig 6 respectively. Note that in both cases the initial characterization curve has a ‘concave up’ slope while the characterization curve with the fast cooldown is ‘concave down’.

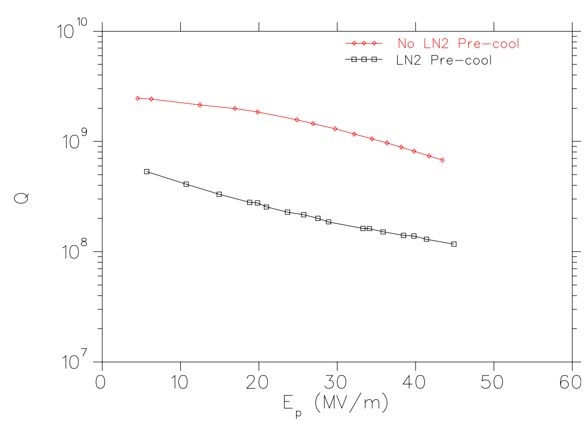

Figure 5: Summary of test results for cavity 9.

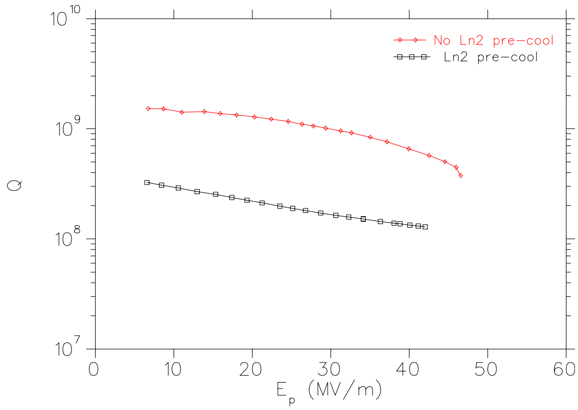

Figure 6: Summary of test results for cavity 12.

What is the origin of the Q-disease in the BCP cavity. The J-lab polishing process is very well controlled and the temperature of the bath remains below 15°C. It is suspected that the hydrogen is picked up during fabrication. In any case the ISAC-II refrigeration plant is large enough that fast cooldowns should not be a problem. The cryomodule is equipped with a helium supply manifold that delivers cold helium to the bottom of each cold mass element to provide efficient cooling. With moderate flows of 100ltr/hr the cavities can be cooled form 200K to 50 K in less than 1 hour.

ELECTRO-POLISHING

Two cavities initially receiving BCP of 130μm at J-Lab were taken to Argonne for further electro-polishing after their initial cold tests. The first cavity (cavity 11) was one of the best cavities with a $Q_o = 2\times10^9$, a peak surface field of 60 MV/m and a peak magnetic field near 120 mT. The second cavity (cavity 7) was an initial poor performer made worse by some hand polishing after the initial test. Cavity 11 results are shown in Fig. 7. The cavity was placed upside down so that the rf volume was used as a bath for the acid. An Aluminum electrode was placed between the inner and outer conductor. The geometry enhanced the removal near the high field end of the cavity around the beam ports. The removal was estimated to be $\sim 60\mu$m at the root end and $\sim 180\mu$m at the beam ports. The cavity after BCP showed test results with moderate Q-slope. After E-P the cavity was tested with LN2 pre-cool and showed a poor result. It was suspected that the cavity had Q-disease so the test was repeated with no LN2 pre-cool but only radiation cooling followed by fast LHe transfer. In the second result the cavity was recovered with a slightly lower Q_0 than the original BCP result but with a reduced Q-slope compared to the BCP surface finish. The knee in the Q-slope at high field is due to field emission. The results are not conclusive but there are some indications that the E-P treatment could lead to a slightly better high field performance. However for cw operation cavities operate well below maximum field limits so that enhanced performance at the highest fields are not worthwhile. Cavity 7 with an etch of 25-75μm was improved by the electro-polish but the final result shows the characteristics of Q-disease and so it is planned to retest the cavity with fast cooldown.

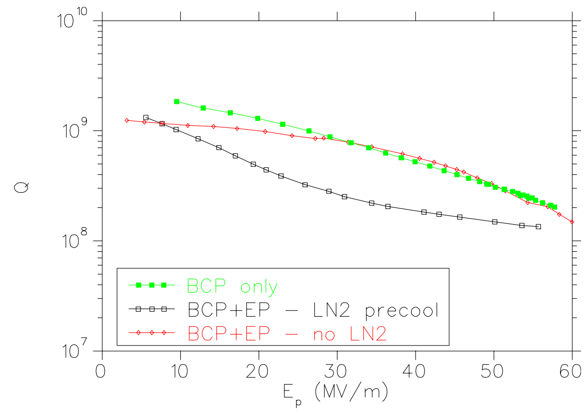

Figure 7: Summary of test results for cavity 11.

One negative feature of the adopted electro-polishing procedure is that the treatment produces a large frequency shift. The frequency shift for cavity 7 and cavity 11 were 110 kHz and 168 kHz respectively. This can be compared to the typical frequency shift for 130μm BCP of 12 kHz. Three dimensional rf modeling shows that a removal of 100μm taken preferentially from the top half (high current) or bottom half (high field) lead to frequency swings of -179kHz or +191 kHz respectively. Uniform etching as with the BCP process will result in only limited frequency shift. Since the E-P treatment method employed here etches so much more effectively at the beam port end the cavity frequency is raised dramatically. Due to the unremarkable performance gains especially considering cw operation and large frequency swing TRIUMF has chosen BCP as the treatment method for the ISAC-II cavities. It is planned to add a treatment facility in the the next year.

ACKNOWLEDGEMENTS

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