PRELIMINARY TEST RESULTS FROM 650 MHz SINGLE CELL MEDIUM BETA CAVITIES FOR PROJECT X*

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Abstract

We have fabricated two single cell 650 MHz β = 0.61 cavities of a JLab design [1], which possibly can be used for the proposed Project X proton linac application. Both cavities were manufactured at JLab from RRR>250 niobium sheet of 4 mm thickness using standard techniques such as deep drawing, electron beam welding, buffered chemical polishing, hydrogen degassing heat treatment, high pressure ultrapure water rinsing and clean room assembly. A detailed description of the design and fabrication procedures is forthcoming [2].

Initially cavity #1 was – after final surface treatment by buffered chemical polishing (BCP) – measured without any provisions for stiffening. As expected, the pressure sensitivity and the Lorentz Force detuning coefficients were relatively high; however, the RF performance was very encouraging: the cavity exhibited a Q-value > 10^{11} at 1.6K, corresponding to a residual resistance of < 1.5 nΩ. The initial gradient was limited to E_{acc} ~ 18 MV/m, limited by field emission.

In a subsequent test, the cavity was re-rinsed and stiffened up, resulting in a somewhat improved mechanical behavior, but no improvement in rf performance. The second cavity was also tested twice- before and after low temperature baking. The results from all tests are reported in this contribution.

INTRODUCTION

Project X is a multi-MW proton accelerator - complex proposed to be built at Fermi National Accelerator Laboratory based on a CW H^- linac utilizing superconducting cavity technology. In the present early design stage many national laboratories as well as international partners from Indian, European and Asian institutions are supporting this effort.

The presently proposed layout as outlined in the P5 report of the High Energy Physics Advisory Panel envisages three low beta, 325 MHz spoke cavity sections, two families of medium beta (0.61 and 0.9), 650 MHz elliptical–type 5-cell cavities and a final beta=1 section of 1300 MHz 9-cell ILC-type cavities. J Lab has proposed a 5-cell cavity design for the beta=0.61 section as an alternative to an existing FNAL design. One of the major differences of the JLab design to the FNAL designs an increased beam aperture, which has some advantages with respect to cell-to-cell coupling, mechanical stability, less field flatness distortions, chemical surface treatment, reduced possibility for HOM trapping and HOM field tilts to name a few. However, this larger iris diameter does not come without the expense of sacrificing some the rf properties of the structure. In table 1 the major properties of both designs are listed:

Table1: Comparison between a JLab and FNAL 5-cell, β=0.61 cavity design for Project X

Parameter	Unit	JLab	FNAL
# of cells		5	5
Frequency	MHz	650	650
Iris aperture	mm	100	83
Equator diameter	mm	380.4	389.9
Active length	mm	694	705
c-to-c coupling	%	1.4	0.75
G	Ω	190	191
R/Q	Ω	296.6	378
E_{peak}/E_{acc}		2.71	2.26
B_{peak}/E_{acc}	mT/(MV/m)	4.78	4.21

CAVITY FABRICATION

Both cavities – "A" and "B" – were fabricated from 4 mm thick high purity niobium sheet of RRR>300 by standard fabrication techniques:

After the deep drawing of the half cells from round discs, the half cells were trimmed for iris and equator butt welds. Beam pipes were rolled from reactor grade niobium and welded along the seams. After trimming and attachment of the flanges made from NbTi flanges by EWB they were welded to the half cells with an interpenetrating inside/outside electron beam weld. Prior to the final equator weld the half cell subassemblies were inspected for surface imperfections, which were removed by mechanical grinding with a fibrous wheel with embedded Al_2O_3.

During the fabrication sequence the mechanical dimensions were carefully monitored and the frequencies of the half cells were recorded. This information is of importance for the fabrication of multi-cell cavities, if one wants to minimize the amount of "after fabrication" tuning to achieve the appropriate frequency and a "flat" field.

In preparation for the cryogenic testing the cavities received a bulk removal of the damage layer by BCP (app. 250 μm) and a 600C, 10 hr hydrogen degassing heat treatment. Wall thickness measurements at 12 points on the cavity surface were carried out before and after the bulk chemistry to determine the actual material removal.

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FINAL TREATMENT AND TESTING

Prior to the cryogenic testing, both cavities received the same final surface treatment after the hydrogen degassing: an ultrasonic degreasing in soap/water solution ("Micro") was followed by 50 µm of BCP, rinsing in hot and cold water and a subsequent high pressure ultrapure water rinsing (HPR).

The respective cavity was dried in our class 10 clean room for app. 12 hrs before the auxiliary parts (input coupling probe/pump-out port and transmission probe), which were carefully clean by blowing off remaining particles with nitrogen, were attached with AlMg- gaskets. The cavity was attached to the test stand (see Figure 1) in front of a laminar flow wall and evacuated for $\geq$ 12 hrs.

Figure 1: Cavity assembled to test stand; as discussed below, an attempt was made to stiffen up the cavity with Ti rods.

Cavity "A"

This cavity was tested and assembled three times; between the tests only HPR was applied.

Test #1

The cavity vacuum prior to cooldown was p=1.2 x10^{-8} mbar and improved to < 5 x10^{-9} mbar at 4.2K. During this test the Q-value was measured between 4.2K and 2K to derive the temperature dependence of the surface resistance. Simultaneously data for the pressure sensitivity of the cavity were taken. At 2K then the Q-value as a function of the accelerating gradient was measured.

Two circumstances made the test quite difficult: the Q_{ext} of the input probe was quite high, which challenged the rf system (locking the cavity), especially – as it turned out – since the frequency of the cavity shifted significantly with decreasing He- bath pressure. Additionally, the Q-value of the cavity was unexpectedly very high at the lower temperatures and e.g. at 2K the bandwidth of the cavity was only ~ 1/100 Hz. However, this circumstance reduced the error of the Q- measurement, because a large part of Q_0 came from the decay time and errors in coupling factor Measurements were minimized. Therefore, the high Q-values are quite believable. Figure 2 shows the best fit of the R(T) data to the BCS theory, based on the program of ref. [3].

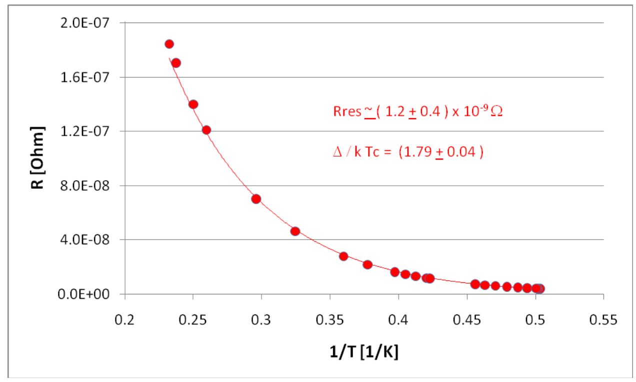

Figure 2: Temperature dependence of the surface resistance; the values for residual resistance and energy gap are obtained from a best fit to BCS with fixed parameters for T_C=9.25K, coherence length ξ = 62 nm and London penetration depth λ_L = 32 nm.

As shown in Figure 3, the cavity frequency shifted significantly with decreasing He bath pressure. Resulting in a sensitivity coefficient of $\Delta f/\Delta p$ ~ -4.4 kHz/mbar. Because of the large frequency shifts an attempt was made in the subsequent tests to stiffen up the cavity as discussed below.

At 2K the Q_0 vs E_{acc} curve was measured; as can be seen in figure 4 the initially high Q-value of 4 x 10^{10} degraded rapidly at ~ 11 MV/m, caused by a combination of strong field emission, which initially processed quite rapidly, and insufficient helium level in the dewar. Because of time constraints the test was aborted and a 2nd test with increased input coupling was carried out.

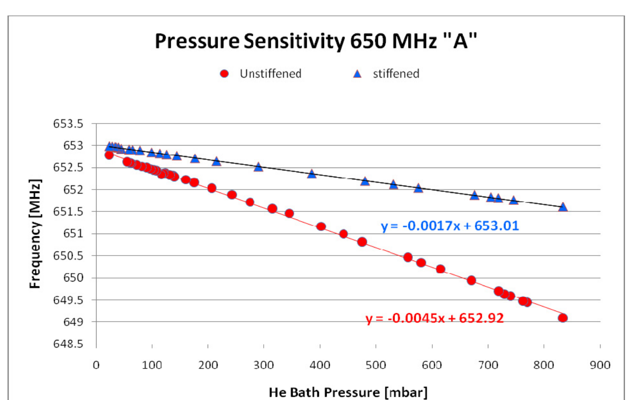

Figure 3: Pressure sensitivity of the single cell cavity, without stiffening and with stiffening (Figure 1) as discussed below.

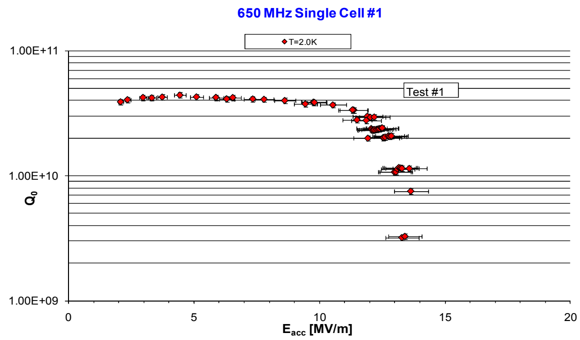

Figure 4: Q_0 vs E_{acc} in the first test with cavity “A”.

The rather high Lorentz Force detuning of ~ -63 Hz/(MV/m)^2 for the unstiffened cavity ”A” and the slight improvement for the stiffened cavity ”B”, test #1 (see below) is shown in figure 5:

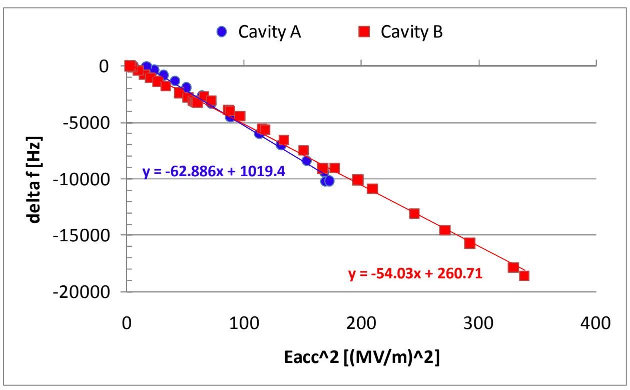

Figure 5: Lorentz Force detuning for the unstiffened cavity “A” and the stiffened cavity “B”. The stiffening did not significantly improve the mechanical properties of the cavity.

Test #2

After disassembly, adjustment of coupling probes, re-rinsing and re-assembly the cavity was tested again in a second test, this time with stiffeners as shown in Figure 1. Vacuum conditions were very similar to the one’s in test #1.

In this test the bath temperature was lowered to 1.6K in order to get more data points for the R(T) evaluation.

Unfortunately, the cavity was now heavily overcoupled; but nevertheless, the high Q_0-values from test #1 were re-confirmed, and at 1.6K the Q_0 exceeded a value of 10^{11}. This is one of the highest Q_0-values obtained on a niobium cavity. Data for Q_0 vs E_{acc} were taken at three temperatures - 2K,1.8K and 1.6K. Because of the excellent cavity performance with respect to Q_0, the cavity was tested subsequently with the SNS 805 MHz rf system – the initial test were carried out with our R&D rf system. Here, a relatively light multipacting barrier appeared between 7-8 MV/m, which could be processed within ~ 30 min.

Within the rather large error bars caused by the highly overcoupled condition of the cavity, both rf systems gave comparable results, giving confidence in the measured cavity performance. Figure 6 shows Q_0 vs E_{acc} as measured with the R&D system. Added to the graph is the measurement with the 805 MHz system at 2K. It became obvious that the stiffening attempt was not very successful with respect to the Lorentz force detuning – see Figure 5, comparing the results for both stiffening cases. This is no real surprise, since the deformations due to Lorentz forces take place at the cells and an effective stiffener has to be attached between cells and beam pipes. Similarly, the pressure sensitivity was not significantly affected and only a factor of ~ 2.6 could be obtained as shown in Figure 3.

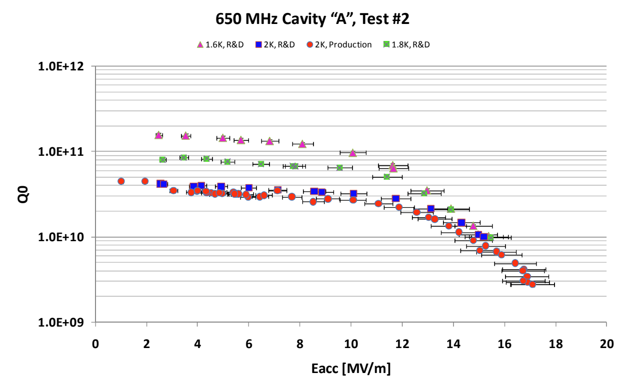

Figure 6: Q_0 vs E_{acc} at 2K, 1.8K and 1.6K. Added in the figure are the data at 2K taken with the 805 MHz “production” system.

Test #3

For this test the Q_{ext} of the input coupler was re-adjusted to a value of ~ 2 x10^{10} ; the cavity went through the same procedures as in test #2 – only HPR was applied in anticipation of reducing the onset of field emission. However, no improvement could be realized. As a matter of fact, the residual resistance had nearly doubled, resulting in a Q – degradation at 2K to Q_0 ~ 3 x 10^{10} and the cavity exhibited this time a strong MP barrier at 7-8 MV/m, which would not process. Therefore the test was aborted and in a future test we are planning to improve the cleaning and assembly procedures.

Cavity “B”

This cavity received for the initial test the same treatment as cavity “A”. Consequently, its behavior was not very different from cavity “A”: the Q- value at 2K was somewhat lower – Q_0 (2K) ~ 3 x 10^{10} – still corresponding to a residual resistance $\leq$ 3 x 10^{-9} Ω . The MP barrier around 8 MV/m processed rather easily and a gradient of E_{acc} ~ 19 MV/m was reached, limited by FE in the absence of a quench, which raised the expectations of higher gradients after a 120 C “ in situ” baking. The result after the application of the baking is shown in Figure 7 together with the initial performance. As can be seen, not only was a significant Q-value improvement realized, but also a higher gradient was measured. The Q-degradation at the high field is to a large extend caused by the "Q-drop" (H_{peak}~ 100 mT) added by some field emission.

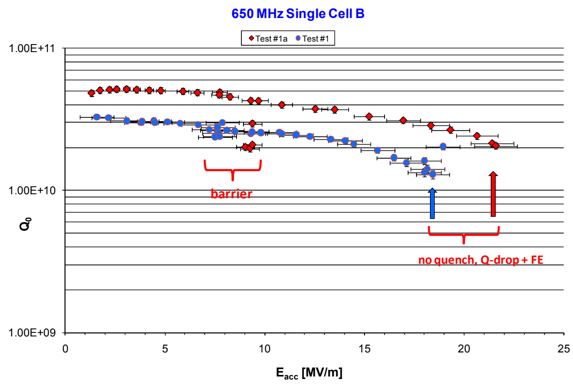

Figure 7: Performance of cavity "B" in test #1, T = 2K.

SUMMARY AND CONCLUSION

Both cavities of the JLab design performed quite well – in particular very high Q_0-values (low residual resistances) were obtained. In Cavity "A" a seldom achieved $Q_0 > 10^{11}$ was measured at 1.6K. It is not yet clear, why both cavities exhibited these low residual resistances compared to more common values of a factor of ~2-3 larger [4]; however, during the fabrication and during the subsequent handling, treatment and final surface preparation, meticulous care was taken of the niobium surfaces and the high Q_0-values might be the result of this.

As the test results showed, both cavities suffered from field emission and one of the goals for future tests is to extend the onset of field emission by improved rinsing and assembly procedures. On the other hand one should not forget, that the highest field obtained in test #1 with cavity "B" corresponds to a surface electric field of E_{peak} >51 MV/m. None of the cavities quenched, which raised the expectations of further improvements in E_{acc}.

As expected, the single cell cavities are mechanically not very stable, presumable because of the flat cell profile, which resulted in large coefficients for pressure sensitivity and Lorentz Force detuning. However, for prototyping stiffening was ignored with the intention to simplify the fabrication while scrutinizing RF properties. From the beginning it was however considered mandatory to stiffen the 5-cell cavities e.g. as practiced for ILC/TESLA cavities or SNS structures. We hope to receive funding to fabricate a multi-cell structure based on these initial encouraging results.

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REFERENCES

[1] F. Marhauser, "A Medium-Beta 650 MHz cavity design for Project X", JLab-TN- 10- 043.
[2] F. Marhauser et al.; IPAC 2011 to be published.
[3] J. Halbritter, "FORTRAN Program for the computation of the surface impedance of superconductors", KFK-Extern 3/70-6, Karlsruhe, 1970.
G. Ciovati, "SUPERFIT: a Computer Code to Fit Surface Resistance and Penetration Depth of a Superconductor", Jefferson Lab Technical Note, TN-03-003, 2003.
[4] G. Ciovati et al., "Residual resistance data from cavity production projects at Jefferson Lab", ASC2010, (2010).