FIRST CRYOGENIC TESTS WITH JLAB'S NEW UPGRADE CAVITIES*

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Abstract

Two types of 7-cell cavities have been developed for the upgrade of CEBAF to 12 GeV. The High Gradient type (HG) has been optimized with respect to the ratio of E_{peak}/E_{acc}. The Low Loss (LL) type has optimized shunt impedance and improved geometric factor. Each cavity type features four DESY–type coaxial Higher Order Mode (HOM) couplers and a waveguide input coupler. Design goals for these cavities have been set to $E_{acc} = 20$ MV/m with an intrinsic Q_o of $8\cdot10^9$ at 2.05 K. A niobium prototype of each cavity has been fabricated at JLab and both cavities have been evaluated at cryogenic temperatures after appropriate surface treatment. In addition, pressure sensitivity as well as Lorentz force detuning were evaluated. The damping of approximately 20 HOMs has been measured to verify the room temperature data. Several single cell cavities were tested in addition to multi cell cavities. We present in this contribution a summary of tests performed on the prototypes of the proposed cavities.

INTRODUCTION

The rationale for developing two different types of cavities for the upgrade of CEBAF to 12 GeV has been discussed in a previous paper [1] and will be repeated only briefly here. Typically, superconducting niobium cavities are limited in their high field performance by field emission. By optimizing the geometry, the ratio of the surface electric field E_{peak} to the accelerating field E_{acc} can be reduced for a given onset of field emission. The HG cavity has this ratio of $E_{peak}/E_{acc}=1.89$ making it less sensitive to the field emission phenomenon. A reduction in the cryogenic losses of a cavity can be achieved by maximizing the shunt impedance R/Q and the geometry factor G. These optimised parameters result in lower stored energy and wall losses at a given accelerating gradient compared to non-optimized cavity shapes. Given a fixed cryogenic capacity of the LHe plant higher end energies can be achieved in the CEBAF accelerator with such cavities (LL).

In Figure 1 the shapes of inner cells of both "upgrade" cavities developed at JLab are compared with the original cavities used at present in the accelerator. Table 1 lists their rf parameters.

CAVITY FABRICATION AND SURFACE TREATMENT

Several single cell cavities and one 7-cell cavity of each type were fabricated from high purity niobium with a RRR value of ~250 by the standard method of deep drawing of subcomponents and electron beam welding.
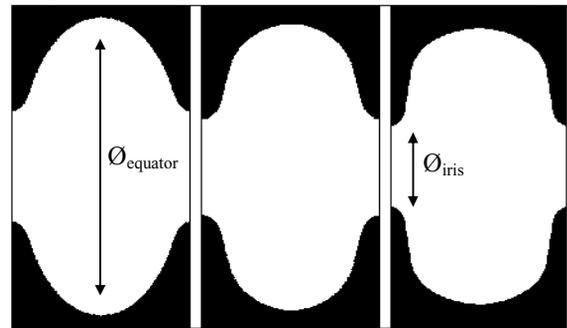

Figure 1: Geometry of the inner cells of the "original CEBAF" (OC) shape and the HG and LL shapes.

Table 1: Parameters of inner cells

Parameter		OC	HG	LL
$\varnothing_{equator}$	[mm]	187.0	180.5	174.0
$\varnothing_{iris}$	[mm]	70.0	61.4	53.0
k_{cc}*	[%]	3.29	1.72	1.49
E_{peak}/E_{acc}	[-]	2.56	1.89	2.17
B_{peak}/E_{acc}	[mT/(MV/m)]	4.56	4.26	3.74
R/Q	[Ω]	96.5	111.9	128.8
G	[Ω]	273.8	265.5	280.3
R/Q·G	[Ω·Ω]	26422	29709	36103

*cell-to-cell coupling

The single cell cavities were used to develop surface treatment procedures and to verify the absence of multipacting as predicted by simulation [2]. The 7-cell cavities (Fig. 2) feature stiffening rings to resist the Lorentz force. At each end of a multi-cell cavity is a Nb55Ti helium vessel end-dish for an integrated helium vessel and two HOM couplers of the DESY type [3]. The coupling of the rf to the cavity is accomplished by a waveguide coupler situated at one beam pipe 80 mm away from the end cell iris. It provides a $Q_{ext} \sim 2\cdot10^7$.

All flanges are made from Nb55Ti and Al_3Mg gaskets are used [4] for sealing.

Figure 2: LL seven cell cavity.

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As fabricated, the cavities had a field flatness of roughly 70%. They have been tuned to > 97 % prior to buffered chemical polishing (BCP). The surface treatment provided a non-uniform material removal (40% less removal at equators) and a non-ideal surface finish with many radial flow marks on the upper half cells, especially on the LL prototype (Fig. 3).

Figure 3: Surface of LL cavity end cells, showing severe flow marks.

The single cell cavities went through several BCP treatments as well as heat treatments and "in- situ" baking cycles. The final treatment, after assembling a cavity in a class 10/100 clean room for a cryogenic test, was always a high pressure rinse with ultra-pure water at a nominal (at the pump) pressure of ~ 80 bar.

EXPERIMENTAL RESULTS

Two LL single-cell cavities with the end-cell and the middle-cell shapes and one HG cavity with end-cell shape have been manufactured. The LL cavities were tested several times as described below.

Tests of LL Cavities #1 and #2

The main purpose of these tests was to find out about potential problems with multipacting and surface cleaning because of the small iris diameter and the relatively flat side wall angle.

Cavity #1 (end-cell geometry): after a nominal material removal of ~ 200 µm, a surface field of E_{peak} ~ 58 MV/m was measured at 2K and no limitations by multipacting were observed. In a subsequent treatment, the cavity was post purified with Ti at 1250 C for 3 hrs; app. 100 micron were removed from the surface and after 1 hr of HPR and horizontal drying in the class 10 clean room for 12 hrs the cavity was re-tested. The performance of the cavity had improved to a surface field of E_{peak} = 63 MV/m, but showed a strong "Q-drop" starting at E_{peak} ~ 45 MV/m. Further improvements were achieved after an "in situ" baking at ~ 100 C for 48 hrs – the "Q – drop" was shifted to a "quench" field of E_{peak} ~ 87 MV/m and was much reduced.

In Figure 4 the cavity performance before baking and after baking is shown; measurements were done at 3 different temperatures. After baking, the Qo vs. E_{peak} curves show the typical three ranges of dependences: a low field Q–slope, an intermediate slope and a high field Q-drop.

In LL#2 (inner cell shape) an E_{peak} of 60 MV/m was measured after ~ 150 µm of material removal by BCP,

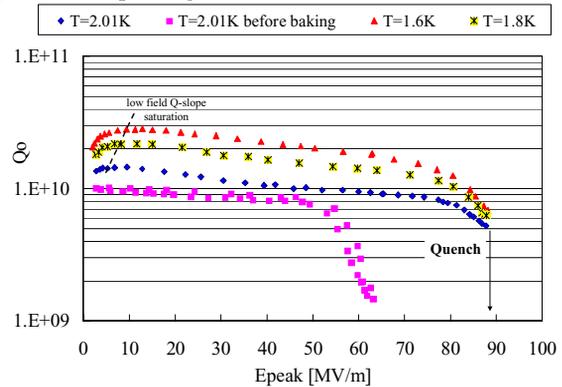however, field emission loading started at ~ 40 MV/m. No signs of multipacting were detected.

Figure 4: Performance of LL single cell cavity #1 after post- purification heat treatment and "in-situ" baking.

HG Cavity (Inner Cell Shape)

The half cells of the HG cavity were electropolished (EP) using the Siemens method [5] prior to welding-on beam pipes and completing the equator weld. Hydrogen degassing at 600 C for 10 hrs followed. We chose this manufacturing method in order to find out whether it is possible to achieve reasonably good cavity performance even if some manufacturing steps remain to be performed and very little final surface treatment can be applied. This might be a valuable method for closed cavities such as e.g. a sc gun cavity. It turned out that the initial cavity performance was rather poor (quenches, low Q), but with subsequent BCP steps continuous improvement in fields was achieved and the cavity eventually improved to E_{peak} ~ 42 MV/m; as indicated in Figure 5. Despite the BCP, the cavity surface remained as shiny as after the initial EP. We conclude at this point that the manufacturing method chosen for this cavity has no advantages over the standard method and that EP should be applied to the full cavity rather than to its parts.
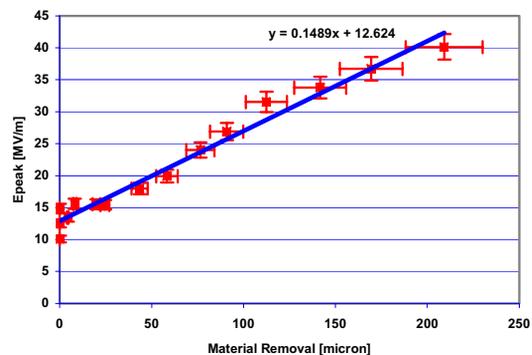

Figure 5: Improvement in quench field with material removal for HG single cell cavity.

Seven Cell Prototypes

HG Prototype

After initial removal of 200 µm of material a heat treatment at 600 C for 10 hrs followed to remove

hydrogen from the preceding chemical treatment. After an additional 50 μm of BCP the cavity reached a gradient of E_{acc} = 21.5 MV/m, limited by field emission, which started at ~ 18 MV/m. In this test the Lorentz force detuning coefficient was measured to be -2.5 Hz/(MV/m)^2. In a subsequent test, rf feedthroughs with copper probe tips were mounted onto the four HOM coupler ports; the test showed unacceptable heating of the probes already at fields as low as 3 MV/m and the Q-value dropped into the 10^8 range at ~4.5 MV/m. After switching off the rf, it took ~ 2 hrs until the low field Q-value was restored as shown in Fig. 6. As a subsequent analysis indicated, several Watts of heat were dissipated in the copper tip and the very poor thermal design of the rf feedthroughs prevented a rapid heat transfer to the helium bath. Efforts are underway to create a thermally superior feedthrough [6] needed for the CEBAF upgrade; it will be used with niobium instead of copper probes.
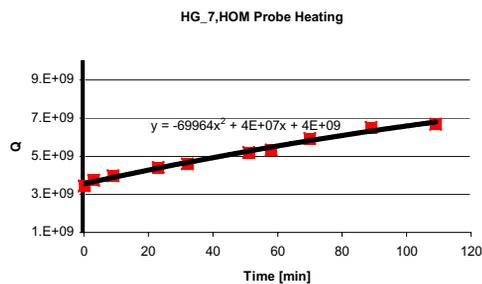

Figure 6: Recovery of the Q-value after probe heating.

LL Prototype

As mentioned already above (see Fig. 3) the surfaces of the LL cavity showed severe flow– and etch– patterns, especially in the end cells. The rf performance of the cavity was disappointing in the fundamental mode and in all modes with high field in the end-cells; strong Q-degradation at fields around 10 MV/m was observed. The end groups were cut off from the cavity to get access to the end cell for mechanical grinding. After this operation and extension of the beam tubes, the cavity reached E_{acc} = 20 MV/m without any signs of multipacting limited by available power because of a strong intermediate Q-slope. We believe that the slope is caused by insufficient material removal after the severe grinding. Additional BCP should improve the situation and is in progress. The Lorentz-force detuning coefficient was measured to be – 3.1 Hz/(MV/m)^2.

HOM damping

The external Q -values of 20 dangerous HOMs were measured at 4.2 K (Fig. 7). For both prototypes the room temperature damping was confirmed.

SUMMARY

Both cavity types for the CEBAF upgrade have been prototyped and – after some unexpected problems with surface treatment, which have been solved on subsequent cavities by flipping – reached the gradient design goal of E_{acc} = 20 MV/m. Improvements in contamination control are necessary to avoid field emission and related Q-degradation. The absence of multipacting in both cavities confirmed the calculations [2]. A severe problem was encountered in the heating of the HOM pick-up probes and a better thermally designed feedthrough is under development. In addition, the analysis of the data from the HG prototype tests indicates that a superconducting probe tip is essential.
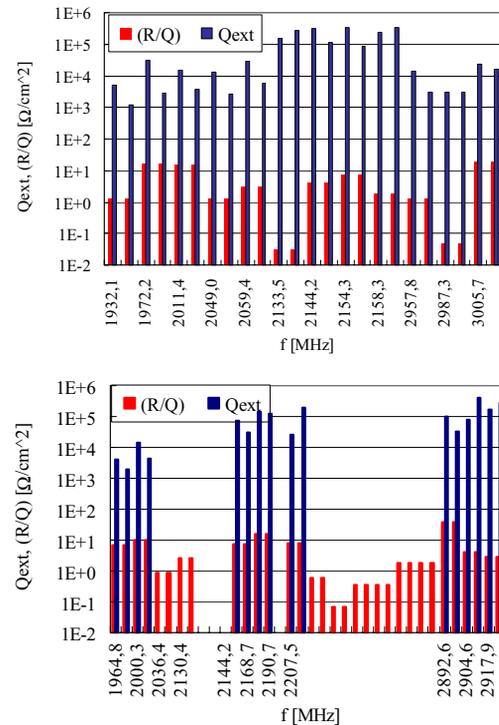

Figure 7: HOM damping at LHe: HG upper diagram, LL lower diagram.

ACKNOWLEDGEMENT

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