PROTOTYPING OF A SUPERCONDUCTING ELLIPTICAL CAVITY FOR A PROTON LINAC*

W. Hartung, J. Bierwagen, S. Bricker, C. Compton, T. Grimm, M. Johnson, D. Meidlinger, J. Popielarski, L. Saxton, R. C. York
National Superconducting Cyclotron Lab, Michigan State University, East Lansing, Michigan
G. W. Foster, I. Gonin, T. Khabiboulline, N. Solyak, R. Wagner, V. Yarba
Fermi National Accelerator Laboratory, Batavia, Illinois
P. Kneisel, Thomas Jefferson National Accelerator Facility, Newport News, Virginia

Abstract

An L-band superconducting cavity has been designed for acceleration of particles travelling at 81% the speed of light ($\beta = 0.81$). Four single-cell prototypes have been being fabricated and tested. Two of these cavities were formed from standard high purity fine grain niobium sheet. The rest were fabricated from large grain niobium. The RF performance of the single-cell cavities indicate that the design is suitable for use in a proton linac; the highest measured accelerating gradient was about 28 MV/m. The fabrication of two 7-cell cavity prototypes is in progress.

INTRODUCTION

Elliptical cavities with $\beta < 1$ are now being used for acceleration of protons in the Spallation Neutron Source (SNS) linac at Oak Ridge [1]. A superconducting cavity similar to the $\beta = 0.81$ cavity for the SNS linac has been designed. Possible applications include a proposed 8 GeV "Proton Driver" linac at Fermilab [2, 3]. The proposed linac at Fermilab would employ 1.3 GHz $\beta = 1$ cavities developed for the TeSLA Test Facility (TTF) [4] at the high energy end. The $\beta = 0.81$ Proton Driver cavity was designed to have the same frequency (1.3 GHz instead of the SNS frequency of 805 MHz) and beam tube diameter (in between the unequal left and right beam tube diameters of a scaled SNS $\beta = 0.81$ cavity) as the TTF cavity.

Following up on the work at Jefferson Lab to investigate the potential of large grain material for cost savings and/or improved RF performance [5], two of the $\beta = 0.81$ single-cell prototype cavities were fabricated from large grain niobium (half-cells made from disks with < 10 grains). Two other cavities were made from the traditional fine grain niobium (grain size of ~ 60 μm). This paper reports on the fabrication and testing of the single-cell prototype cavities.

CAVITY DESIGN

A drawing of the 7-cell cavity is shown in Figure 1, along with the electric field lines calculated by SUPERFISH [6]. Selected cavity parameters from SUPERFISH are given in Table 1. The corresponding values for the TTF [4] and SNS [7] cavities are also included. The wall inclination of the Proton Driver cavity is the same as for the SNS cavity, but the cell-to-cell coupling is slightly higher, allowing for 7 cells instead of 6. The RF parameters of the Proton Driver cavity are similar to the SNS case. More information on the cavity design is available in a separate report [8].

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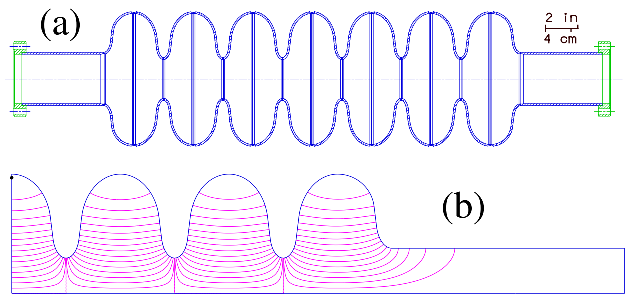

Figure 1. (a) Drawing of 7-cell $\beta = 0.81$ Proton Driver cavity (blue = Nb; green = Nb-Ti). (b) Electric field lines for the right half of the cavity.

Table 1. Selected parameters for the $\beta = 0.81$ Proton Driver cavity and comparison with SNS and TTF cavities; E_a = accelerating gradient, E_p = peak surface field, B_p = peak surface magnetic field, c = speed of light, R = shunt impedance (linac definition), and Q = quality factor.

Cavity	TTF 9-cell	SNS 6-cell	Proton Driver 7-cell	Proton Driver 1-cell
geometrical β	1	0.81	0.81	0.81
wall inclination	13.3°	7°	7°	7°
E_p/E_a	2.0	2.19	2.19	2.18
cB_p/E_a	1.28	1.44	1.41	1.58
cell-to-cell coupling	1.8%	1.5%	1.6%	-
R/Q per cell	115 Ω	80.8 Ω	79.1 Ω	62.3 Ω
Geometry factor	270 Ω	233 Ω	227 Ω	229 Ω

CAVITY FABRICATION AND PREPARATION

Sheet Nb of thickness 2.8 mm was used. Forming of the half-cells and beam tubes was done at MSU and in the local area; electron beam welding was done by industry. Nb-Ti flanges with knife edges were electron beam welded to the beam tubes. Partially welded cavities are shown in Figure 2. The grain boundaries of the large grain half-cell (Figure 2b) are clearly visible.

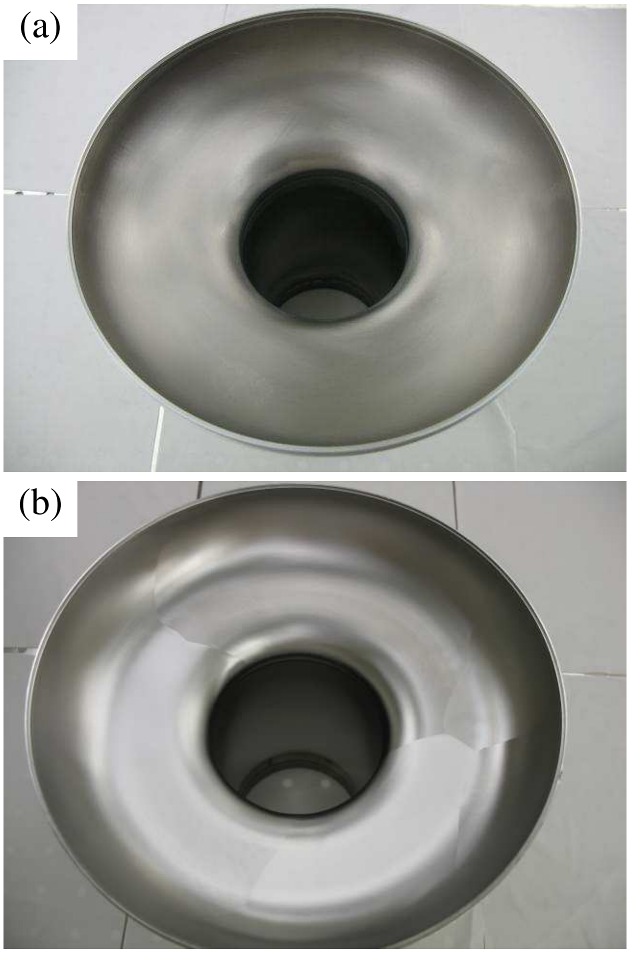

Figure 2. (a) Fine grain and (b) large grain half-cells after the iris weld.

Fine Grain Cavities

Rolled Nb sheet of RRR ≥ 260 was used for the fabrication of the fine grain cavities. Cu gaskets were used with the knife edge seal on the Nb-Ti flanges for the RF tests. Neither the half-cells nor the completed cavities were fired in a vacuum furnace. The cavities were etched with a buffered chemical polishing solution (BCP, chilled 1:1:2 mixture) to remove about 180 μm after fabrication; 30 to 50 μm was removed in the case of repeat etching. Before assembly onto the insert for RF testing, the cavities were high-pressure rinsed with ultra-pure water for 45 to 120 minutes. The first cavity was tested 4 times, with several additional cycles of etching and rinsing. The second cavity was tested twice, with a bake out under vacuum for 12 hours and 20 minutes at 120°C after the first RF test.

Large Grain Cavities

For the fabrication of the large grain cavities, Nb sheet was cut via wire electric discharge machining (EDM) from an ingot with RRR ~ 280 and Ta content ~ 800 ppm. After the iris weld, the half-cells were mechanically polished to smooth off grain boundaries. Prior to the first RF test, the cavities were fired in vacuum at 600°C for 10 hours to eliminate hydrogen from the material. A 50 μm etch (BCP, unchilled 1:1:1 mixture) was done before before firing, and another 50 μm etch was done after firing. Because of issues that arose during the etch, the knife edges were machined off and indium seals were used instead. The cavities were high-pressure rinsed with ultra-pure water for 60 minutes (HPWR). Each cavity was tested 4 times; the preparation steps for the various tests are indicated in Table 2.

RF TESTING

Fine grain cavities were tested at MSU and large grain cavities were tested at Jefferson Lab. Figure 3 shows one of the fine grain cavities on the RF test stand.

Fine Grain Cavities

Results of the various tests on the first fine grain cavity were all similar, as can be seen in Figure 4a. The results of the first test on the second cavity (Figure 4b) were consistent with those of the first cavity, except that the field limit was a bit lower. The vacuum bake-out on the second cavity improved the BCS Q but did not help the high-field performance (Figure 4b). Both fine grain cavities were limited by a hard barrier ("quench"). The highest gradient reached with the fine grain cavities was $E_a = 18$ MV/m, corresponding to $E_p = 40$ MV/m and $B_p = 96$ mT.

Little or no x-ray signals were observed in the RF tests (≤ 600 mrem/hour inside the radiation shield), except in the

Table 2. Preparation of the large grain cavities.

RF Test	Preparation
# 1	see text, no additional heat treatment
# 2	vacuum bake-out for 12 hours at 120°C
# 3	2 hour Ti at 1250°C, 50 μm etch, HPWR
# 4	vacuum bake-out for 12 hours at 120°C

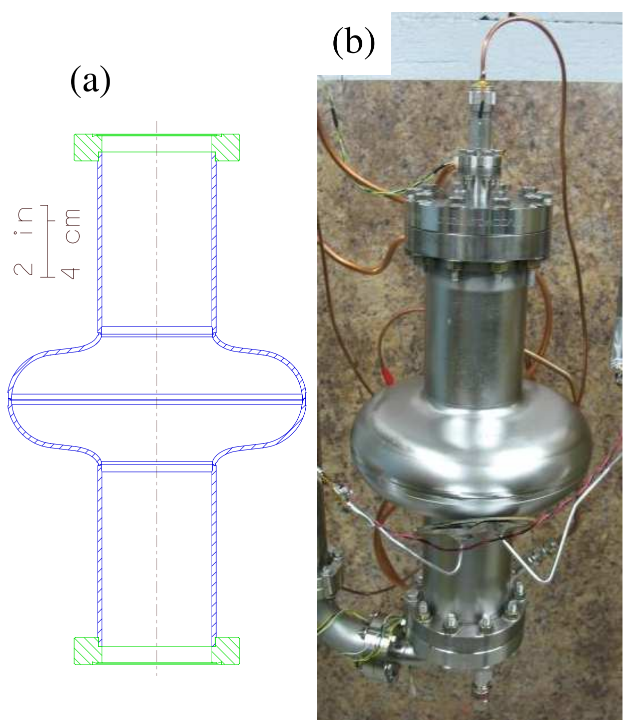

Figure 3. (a) Drawing of single-cell $\beta = 0.81$ cavity. (b) Fine grain cavity on insert for RF test.

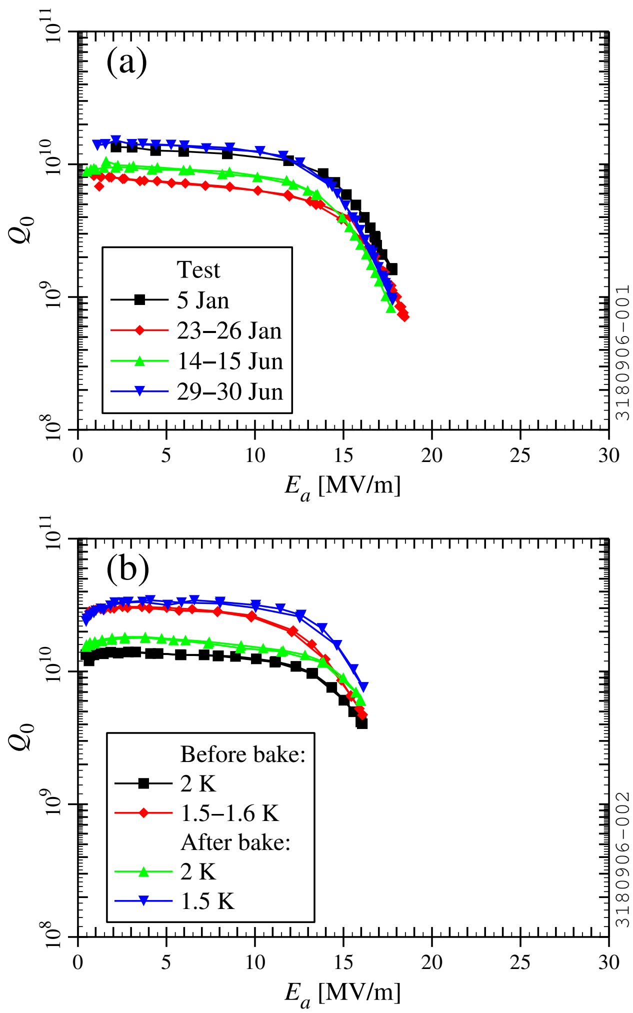

Figure 4. (a) RF test results at 2 K for the first fine grain cavity (no thermal treatment); (b) results for the second fine grain cavity (before and after the 120°C bake-out).

first test on the first cavity, in which heavy field emission was observed and reduced by helium processing.

Large Grain Cavities

Results of the RF tests on the large grain cavities are shown in Figure 5. Both large grain cavities reached higher fields than the fine grain cavities. High field Q-drop was observed, and was eliminated by baking under vacuum. The bake-out also generally reduced the BCS surface resistance, as was the case for the fine grain cavities (and as observed with other cavities). After firing at 1250°C with Ti and vacuum baking, both cavities reached a slightly higher field and were limited by quenches. The highest field reached with the large grain cavities was $E_a = 28$ MV/m, corresponding to $E_p = 62$ MV/m and $B_p = 148$ mT.

Significant field emission was seen in only one test (Test #2 on the second large grain cavity); in this case, the field was limited by high radiation levels. A soft multipacting barrier near $E_a = 15$ to 18 MV/m was seen in some of the tests, along with an increase in radiation levels. The barrier was eliminated after a few minutes of conditioning. Measured low-field residual surface resistances values were between 8 and 14 nΩ, consistent with the fine grain cavities.

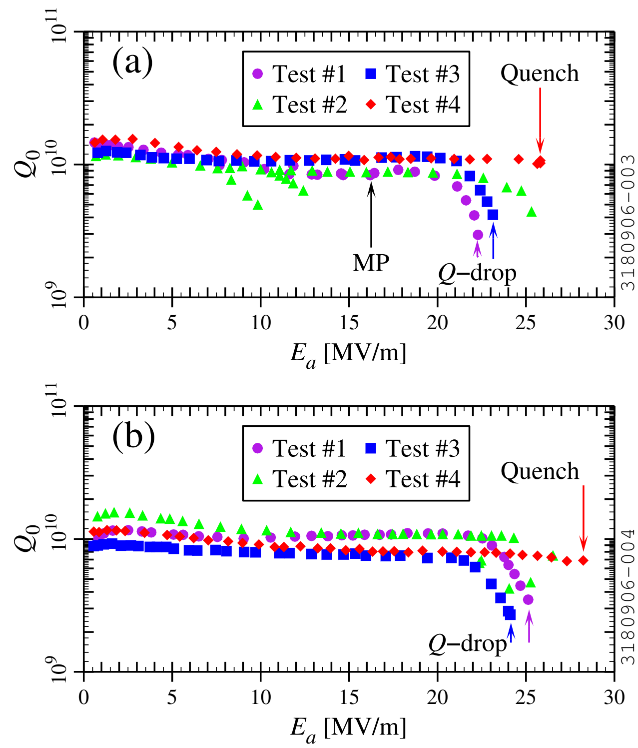

Figure 5. RF test results at 2 K for (a) the first and (b) the second large grain cavities.

CONCLUSION

Reasonable RF performance, adequate for use in a proton linac, was reached in all 4 single-cell 1.3 GHz $\beta = 1$ prototype cavities. The gradients reached in the large grain cavities were about 50% higher than for the fine grain cavities, although the preparation steps were also different. Fabrication of two 7-cell cavities is in progress; one of the 7-cell cavities will be made from fine grain Nb and the other will be made from large grain Nb.

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