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20 MV/m Accelerating Gradient with Heat Treatment of a Six Cell, 1.5 GHz Cavity for TESLA,*

J. KIRCHGESSNER, P. BARNES, W. HARTUNG, M. HILLER†, D. MOFFAT, H. PADAMSEE, D. RUBIN, D. SARANITI††, J. SEARS, Q. S. SHU†††, and M. TIGNER
Laboratory of Nuclear Studies, Cornell University, Ithaca, NY 14853 USA

SUMMARY

In order to use superconducting RF accelerating structures in the construction of a high energy linear collider, the structures must be designed to meet specific goals. These include low peak surface electric fields, good higher order mode power extraction from the ends, maximum accelerating gradient and, above all, low cost per unit accelerating voltage. Such a structure has been designed, manufactured and tested. Preliminary results have been reported.[1] The cavity was then mechanically braced with Niobium braces and then heat treated. The final test gave 20 MV/m accelerating field. Details of some difficulties encountered will also be presented at this time.

INTRODUCTION

At this time in the development of superconducting RF accelerating cavities, the accelerating gradient is limited by two phenomena, electron field emission and thermal breakdown. The first of these makes it imperative to choose a cell shape that minimizes E_{pk}/E_{acc} and the second phenomena to minimize H_{pk}/E_{acc} (the ratio of the peak surface fields to the accelerating gradient). As field emission is the dominant gradient limitation, there is considerable premium in lowering E_{pk}/E_{acc}. The cell to cell coupling (K) is also effected by the shape. This is true of the coupling of the HOM's as well as the fundamental TM_{010} mode. Because of this, the number of coupled cells comprising an accelerating unit is limited. A larger number of cells/module helps reduce the structure cost by reducing the number of couplers as well as by improving the filling factor for the machine. Another consequence of the cell to cell coupling in the TM_{010} mode is the relative ease of tuning the structure to achieve uniform accelerating gradient along the length of the unit.

DESIGN OF THE STRUCTURE

In order to test our ability to produce an accelerating structure which best meets the requirements of a linear collider, a series of calculations were made in which we tried to design the shape of the structure which had the following properties:

- Low E_{pk}/E_{acc}.
- Tolerable cell to cell coupling (K) in the TM_{010} mode.
- More than 5 cells/unit.
- Low cost.
- Tolerable Q_{ext} in all HOM's with couplers on the beam pipe.

Although it is straightforward to reduce E_{pk}/E_{acc} by reducing the beam pipe radius BT, this is undesirable because the transverse wakefields increase as BT^{-3} which makes it more difficult to control multibunch instabilities and meet alignment and vibration tolerances for the linac.

The cavity shape that was manufactured and tested is shown in Figure 1.

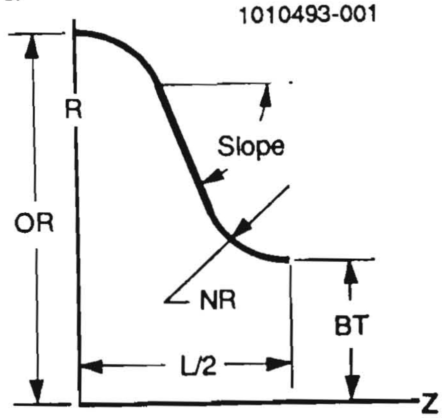

Figure 1.

The five independent variables describing the shape were as follows:

OR, the outside radius.
BT, the beam tube radius.
L/2, the half length of the cell.
NR, the nose radius, and
Slope, the slope of the straight wall segment.

The OR which primarily determines the fundamental mode frequency is adjusted in all cases to obtain the desired frequency. The L/2 value is determined by the frequency as the particles to be accelerated must be kept in phase with the RF oscillations. Namely L/2 must be equal to 1/4 wavelength.

In order to minimize the number of couplers required on the cavity module, the cells were polarized in a manner such that both polarizations of the dipole modes could be damped with one coupler.[2]

CONSTRUCTION

The cavity chosen to best meet the stated requirements was manufactured of 1.5 mm Niobium sheet and was 6 cells long. The number of 6 cells was limited by the available furnace and by the available testing facilities. The cell parameters are shown in Table 1.

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† Babcock & Wilcox, Lynchburg, VA
†† Now at Stanford University, Palo Alto, CA

††† Now at SSC Laboratory

Frequency	1500 MHz
OR(Equator Radius)(average)	9.48 (9.43 ends) cm
NR(Nose Radius)	1.09 cm
BT(Beam Tube Radius)	3.56 cm
Slope	70 degrees
L/2(1/2 cell length)	4.93 cm
Coupling K	1.8%
E_{pk}/E_{acc}	2.1
R/Q	89 ohms /cell
H_{pk}/E_{acc}	57 gauss/MV/meter
Length of Polarizing Segment	1.27 cm
% Freq. Split of TM_{110} mode	2.9% (2.03 GHz)
% Freq. Split of TE_{111} mode	0.22% (2.02 GHz)

Table 1

TESTS OF CAVITY

This six cell niobium cavity (LTP6-1) was initially tested twice. In both tests the structure reached fields of E_{acc}=18 MV/meter with considerable field emission, but final thermal breakdown. These tests were reported in Reference 1 and the curves from these tests are shown in Figure 2.

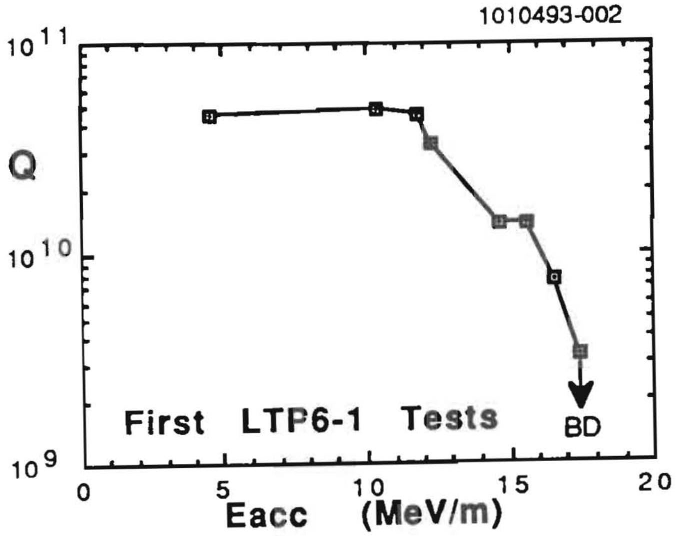

Figure 2

In order to reduce field emission we wished to vacuum fire the structure. Because the cell walls were only 1/16" thick, th: : longitudinal braces were welded to the equator of each of the cells to prevent distortion during firing and collapse during later tests.

In the process of welding on these braces, a gun arc in the EBW (electron beam welder) melted a 1/2" diameter hole in one of the cells. A very careful repair was made and when the cavity was remeasured at room temperature it was found to still retain adequate tune of all cells to give a level field profile.

The cavity was retested at this stage and the results were not very good. There was thermal breakdown at an E_{acc} level of 8-10 MV/meter. This data is shown in Figure 3.

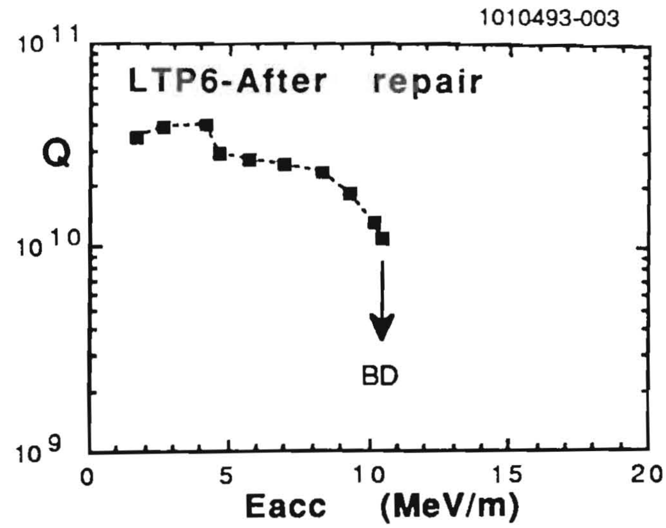

Figure 3

After a heavy etch to hopefully remove the apparent new defect, the cavity was fired for four hours at 1500 deg. C in a standard titanium lined niobium box.[3] After firing, the structure was rinsed, but the titanium was not chemically removed from the outside of the structure. In this test, the E_{acc} value achieved was 15.3 MV/meter. The results of this test is shown in Figure 4.

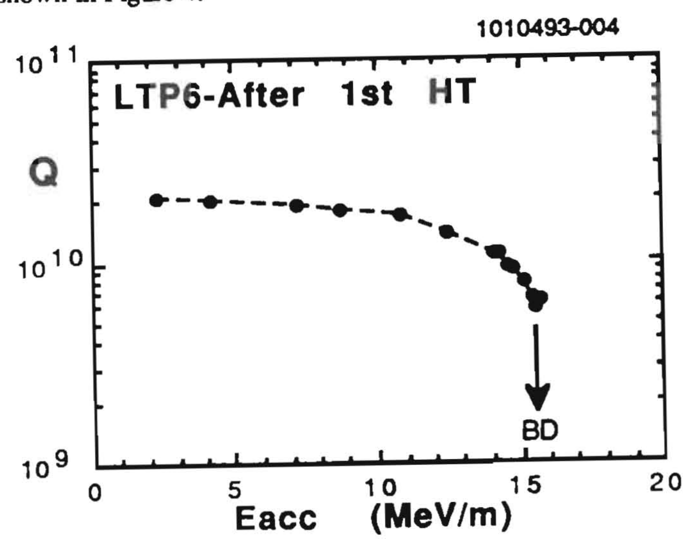

Figure 4

After this test the field flatness was measured to see if the firing had detuned the cavity. The E_{max}/E_{min} cell ratio was measured to be 1.9. This value of cell to cell field variation is excessive. During the firing the braced cavity was suspended from the top beam tube. This caused the top end half cell to be deformed by the force applied to it while the niobium was in the hot, softened condition. It was found that by tuning only the top half cell, that had taken all the cavity weight, the cell fields could be completely leveled.

After this first heat treating, the field level in the cavity was still not quite as high as the field achieved in the first tests. In an attempt to push to higher fields, the cavity was again chemically etched and fired for 4 more hours at 1500 C. After firing, the cavity was tuned in the clean room. This was followed by a Methanol rinse followed by ultrasonic cleaning with Methanol, then a final Methanol rinse.

After mounting, the cavity was again tested and the results are shown in Figure 5.

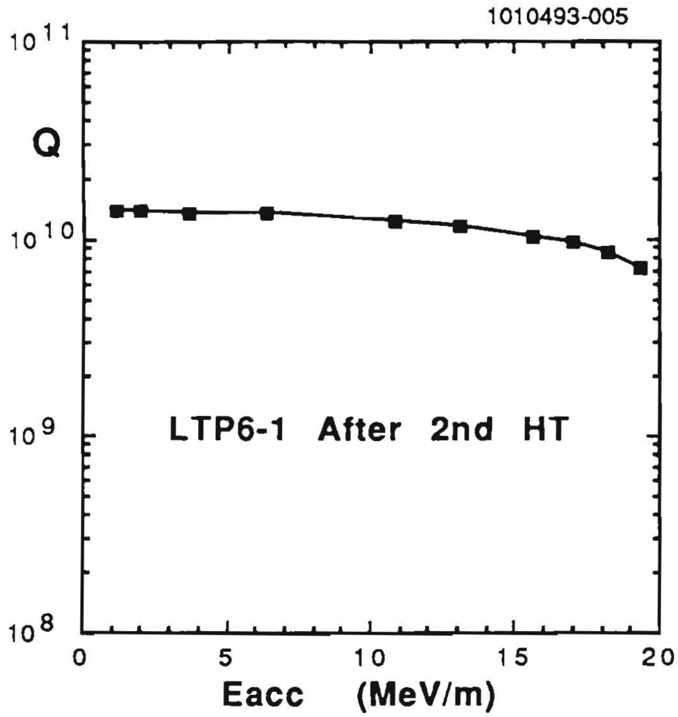

Figure 5

As can be seen, the field level of E_{acc}= 19.5 MV/m at a very good Q value was finally realized.

CONCLUSIONS

Several important lessons were learned in the course of the experiments on this cavity structure. They could be listed as follows:

- The ratio of H_{pk}/E_{acc} must be watched when the cell shape is designed. Since the time when this cavity shape was developed a new shape has been developed for TESLA which does not suffer from this high value of H_{pk}/E_{acc}.
- Sometimes a very good result is achieved on the first test.
- Bracing of the cells is very effective in stabilizing the parts that are braced.
- Furnace treatment with Titanium is effective in increasing RRR and, therefore, raising the thermal breakdown limits.
- Very extensive repairs may be made on the cells with no long term bad effects.
- Chemical cleaning of the structure seems to completely restart history in terms of the surface field emission behavior.
- Polarized cells seem to exhibit no different behavior in the TM_{010} mode by virtue of being polarized.
- Careful records were kept of the costs of the manufacture and treatment of this structure. The total was less than $6000.
- Bead pull measurements can be made on a cavity in a clean room, under clean conditions without introducing excessive field emitters that are difficult to remove.

The experiments with this structure were important steps in the process of achieving high field, low cost superconducting linear collider cavities.

REFERENCES

[1] J. Kirchgessner et. al., Proc. 1991PAC, San Francisco, p 2426

[2] J. Kirchgessner et. al., Proc. 1989 PAC, Chicago, p 479

[3] Q. S. Shu et. al., Proc. 1989 PAC, Chicago, p 491

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An Update on High Peak Power (HPP) RF Processing of 3 GHz Nine-cell Niobium Accelerator Cavities*

J. Graber‡, P. Barnes, C. Crawford†, J. Kirchgessner, D. Moffat, H. Padamsee, P. Schmüser‡, and J. Sears
F.R. Newman Laboratory of Nuclear Studies
Cornell University
Ithaca, NY 14853 USA

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Abstract

Two 3 GHz, nine-cell niobium accelerator structures have been fabricated and tested multiple times. An unambiguous improvement in cavity performance can be shown due to High Peak Power (HPP) RF processing of the cavities. The average achieved accelerating gradient prior to HPP processing was E_{acc} = 12 MV/m, (Standard Deviation = 3 MV/m). The average maximum accelerating gradient following all HPP processing was E_{acc} = 17 MV/m, (Standard Deviation = 2 MV/m). Gains in cavity performance can be directly correlated with magnitude of field reached during pulsed HPP processing. Durability of processing gains has been tested by exposing processed cavities to filtered air, at room temperature, and unfiltered air, under both room temperature and cryogenic conditions. Filtered air had no discernable effect on cavity performance. Unfiltered air degraded cavity performance, through increased emission, however much of the cavity performance could be regained through further RF processing.

I. INTRODUCTION

Superconducting Radio-frequency (SRF) cavities are a promising technology for construction of the next generation of electron-positron colliders. In order for SRF to become a viable method for construction of these machines, however, attainable accelerating gradients must be increased from the 5-10 MV/m attained in present SRF accelerators to 25-30 MV/m.[1] Field emission (FE) of electrons from the RF surface has been the primary limitaion to SRF cavities for the last five to ten years.

The HPP experiment was designed to explore the benefits of high power pulsed radio-frequency (RF) processing as a means of reducing FE loading in 3 GHz niobium accelerator cavities. RF processing is a method of cavity conditioning, where the cavity is exposed to high RF fields in the absence of a particle beam. The HPP apparatus can deliver up to 200 kW peak power for millisecond pulse lengths during processing.

Early results with HPP (presented previously[2],[3]) showed significant reduction in FE loading in single-cell cavities. It is also important to verify that the HPP technique can successfully reduce FE loading in multi-cell structures as well as it does in single cavities. Two nine-cell cavities were constructed and tested several times each. Between successive tests on a cavity, an acid etch was performed, removing approximately 10 microns from the RF surface. Past studies lead us to believe that retesting following etching is equivalent to testing a new cavity. A complete description of the HPP experiments can be found in the Ph.D. dissertation associated with this work.[4]

II. OVERVIEW OF NINE-CELL RESULTS

In this paper, we will show that HPP is successful in improvement of low power, continuous wave (CW) behavior of the nine-cell cavities. To support this conclusion, we report on investigation of cavity performance before and after HPP processing, as well as correlation of the improvements with the characteristics of HPP processing.

Figure 1 is a histogram comparison of attainable CW accelerating gradient, before and after HPP processing. HPP processing improved the mean attainable gradient from 12 MV/m to 17 MV/m, an increase of 41%.

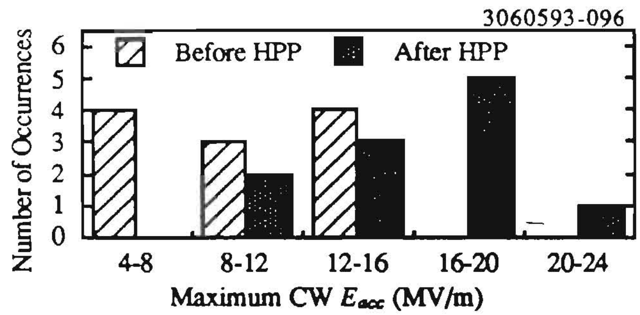

Figure 1. Histogram plot of maximum achieved CW accelerating gradient, before and after HPP processing. Without HPP, $\langle E_{acc} \rangle$ = 11.9 MV/m (s.d. = 3.4 MV/m). With HPP, $\langle E_{acc} \rangle$ = 17.0 MV/m (s.d. = 2.1 MV/m).

Figure 2 is a histogram comparison of X-ray detection threshold gradient, before and after HPP processing. X-rays are produced when emitted electrons impact elsewhere on the cavity surface. The onset of X-rays is a reproducible method of detecting the onset of FE. HPP processing improved the

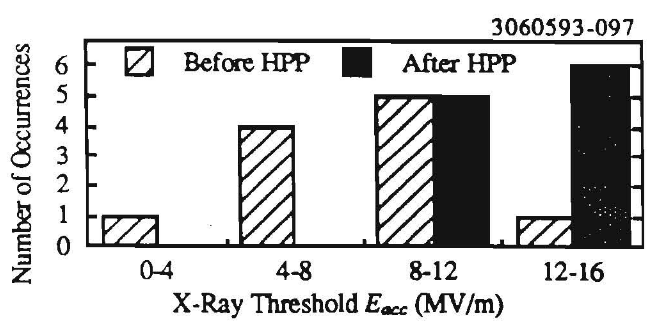

Figure 2. Histogram plot of X-ray threshold accelerating gradient, before and after HPP processing. Without HPP, $\langle E_{acc} \rangle$ = 7.5 MV/m (s.d. = 1.3 MV/m). With HPP, $\langle E_{acc} \rangle$ = 12.4 MV/m (s.d. = 1.3 MV/m).

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† Permanent Address: Fermilab, Batavia, IL USA.

‡ Permanent Address: DESY, 85 Notkestrasse, 2000 Hamburg 52, Germany.