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

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]

Supported by the NSF with supplementary support from the U.S.-Japan collaboration.

† Permanent Address: Fermilab, Batavia, IL USA.

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

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%.

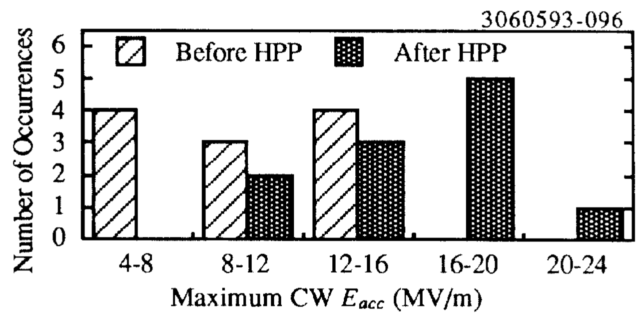

Figure 1. Histogram plot of maximum achieved CW accelerating gradient, before and after HPP processing. Without HPP, $\langle E_{acc}\rangle$ = 11.9 MV/m (s.d. = 3.4 MV/m). With HPP, $\langle E_{acc}\rangle$ = 17.0 MV/m (s.d. = 2.1 MV/m).

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

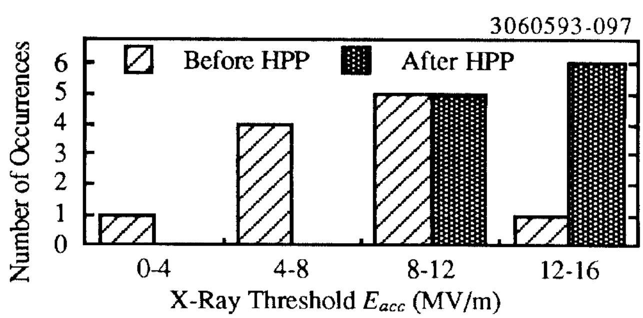

Figure 2. Histogram plot of X-ray threshold accelerating gradient, before and after HPP processing. Without HPP, $\langle E_{acc}\rangle$ = 7.5 MV/m (s.d. = 1.3 MV/m). With HPP, $\langle E_{acc}\rangle$ = 12.4 MV/m (s.d. = 1.3 MV/m).

X-ray threshold gradient from 7.5 MV/m to 12.4 MV/m, an increase of 65%.

Figure 3 shows a composite plot of the Q_0 vs E_{acc} plots of the best six experiments with nine-cell cavities. When the FE threshold is exceeded in a cavity, the dissipated power grows exponentially with increasing electric fields, causing the severe drop in Q_0, as shown in Figure 3.

III. ANALYSIS

Given the success in improving CW behavior of the nine-cell cavities, we would like to characterize the success with relation to the terms of the HPP parameters. A clear correlation can be shown between the electric field reached during HPP processing (E_{HPP}) and the subsequent CW cavity performance. Figure 4 is a plot of maximum attained field as a function of E_{HPP}. Figure 5 is a plot of X-ray threshold as a function of E_{HPP}. In these plots we see that increasing E_{HPP} generally leads to reduced FE, and therefore increased attainable accelerating gradients. During HPP, the input power, loaded Q, and pulse length are adjusted to maximize E_{HPP}. We additionally found that in any individual experiment, when E_{HPP} stopped improving, no further reduction of FE was achieved. Q_0 values are estimated to drop as low as 10^6 during HPP.

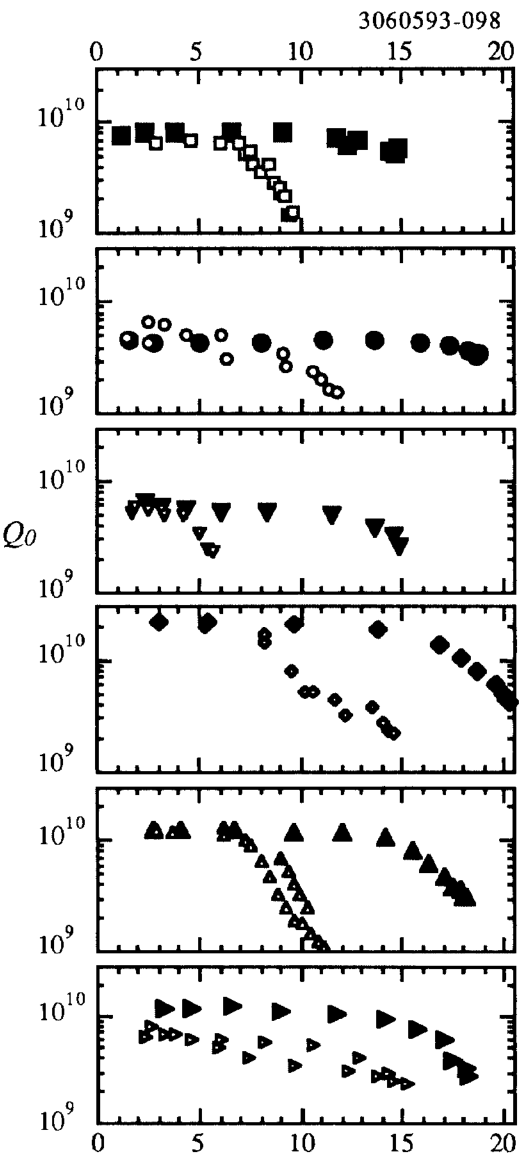

Figure 3. Composite Q_0 vs E_{acc} plots of the six best tests of nine cell cavities. Open symbols show cavity behavior before processing; closed symbols are for after HPP.

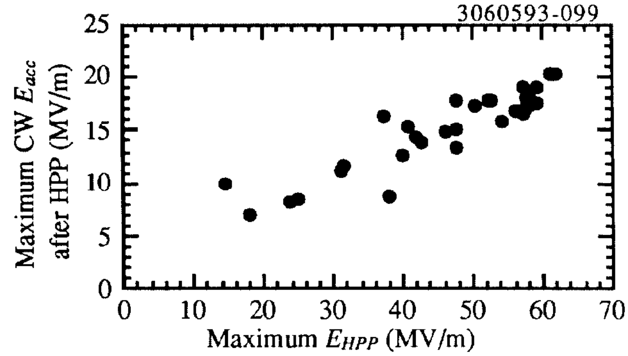

Figure 4. Maximum attained CW E_{acc} plotted as a function of maximum surface electric field during HPP processing.

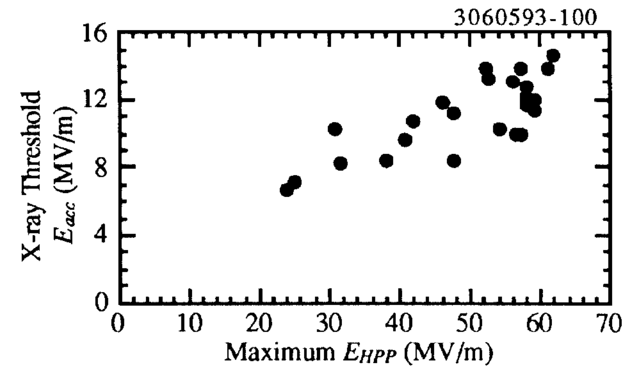

Figure 5. CW FE loading threshold E_{acc} plotted as a function of maximum surface electric field during HPP processing.

The current working model for RF processing states that processing occurs when the electric fields are driven sufficiently high so as to induce an emission current which is strong enough to cause melting and/or vaporization of the emission site. This model is supported by the correlation of processing success with E_{HPP}. The microscopic effects of RF processing are more fully investigated in another paper presented at this conference.[5]

The primary limitation on E_{HPP} has been determined to be thermal breakdown (or quench), where the RF surface of the cavity is locally heated above the critical temperature. It then becomes normal conducting. Methods of characterizing and overcoming the quench limit are further discussed in another paper presented at this conference.[6]

IV. OTHER RESULTS

A. Durability of Processed Cavities

HPP processing is foreseen as a possible method of cavity preparation for large scale accelerator facilities. In order to show the applicability to this function, it is necessary to learn what care is required for a cavity following processing to maintain the HPP induced benefits. To this end, we allowed a processed nine cell cavity (low field $Q_0 = 1 \times 10^{10}$, $Q_0 > 10^{10}$ for E_{acc} = 14 MV/m, maximum E_{acc} = 18 MV/m) and cycled it to room temperature. While at room temperature, the cavity was exposed to filtered air (0.3 micron HEPA filter) for 24 hours, and then re-evacuated. The cavity was then re-cooled to liquid helium temperature, and the FE behavior was measured. Figure 6 shows the Q_0 vs. E_{acc} plots before and after this exposure. No significant change in FE loading is seen.

This is consistent with the findings of RF processing studies performed on low frequency, heavy ion accelerator cavities at Argonne National Laboratory[7], as well as low power processing of 1.5 GHz cavities at Cornell LNS.[8]

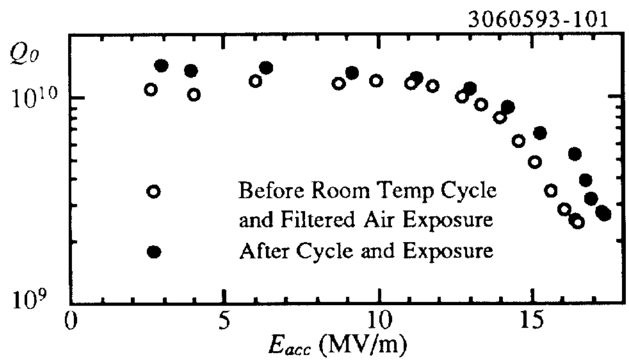

Figure 6. Q_0 vs. E_{acc} plots showing nine-cell cavity behavior before and after a room temperature cycle, with exposure to filtered air. No significant change in FE behavior is measured.

B. Recovery from Vacuum Accidents

Vacuum accidents are an ever present danger in accelerator systems, and the contamination due to such an accident can cause significant degradation of the performance of an accelerator cavity. In this light, we present the results of two exposures of nine cell cavities to unfiltered air, one accidental and one intentional.[9] It has been established previously that air, especially unfiltered air, is a source of field emitters.[8],[10]

The circumstances of the first accident were: At T = 4.2 K, the cavity was exposed to the vacuum pumps which are used to evacuate the experimental dewar in order to reduce the temperature to 1.4 K. Following re-evacuation of the cavity, the experiment was begun. The Q_0 vs. E_{acc} plots are shown in Figure 7. The initial rise of power was characterized by very heavy FE, some of which was processable with low power. The second curve in Figure 7 is the reproducible Q_0 vs. E_{acc}, following all possible low power processing. The cavity was then HPP processed with power as high as 90 kW, and fields as high as E_{peak} = 58 MV/m. The HPP processing was not only successful in reducing the FE loading, but it also seemingly improved the low field Q_0 value, possibly through RF removal of resistive contaminants on the cavity surface.

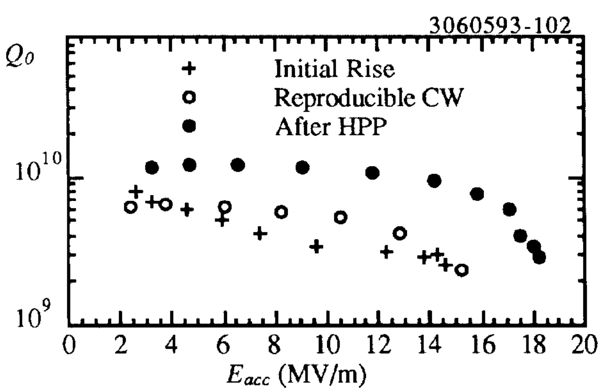

Figure 7. Q_0 vs. E_{acc} plots showing nine-cell cavity behavior before from the first vacuum accident.

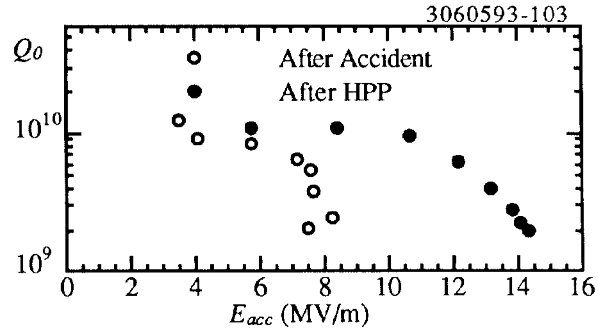

Figure 8. Q_0 vs. E_{acc} plots showing nine-cell cavity behavior before from the first vacuum accident.

The second event to be reported was an intentional test of a vacuum accident. Following the above described test, the cavity was cycled to room temperature, re-cooled, and re-tested. Then, while the cavity was at liquid helium temperature, the cavity interior was exposed to unfiltered atmosphere. The cavity was then remeasured, showing heavy field emission, as well as a low field Q_0 degradation. Following a room temperature cycle, the cavity was HPP processed, with peak power up to 105 kW, and fields up to E_{peak} = 42 MV/m. Again, partial recovery was made via HPP processing. All Q_0 vs. E_{acc} curves for this experiment are shown in Figure 8.

Based on these results, we conclude that if cavities are damaged by vacuum accidents, the performance may be regained through HPP RF processing, and sometimes with low power.

V. REFERENCES

1 *Proc. of the 1st TESLA Workshop*, Cornell University, Ithaca, NY, CLNS **90-1029** (1990).

2 J. Graber, et al., *Proc. of the 5th Workshop on RF Superconductivity*, D.Proch ed., DESY, Hamburg, Germany, **DESY M-92-01**, 576 (1992).

3 J. Graber, et al., *Proc. of the 1991 Particle Accelerator Conference*, IEEE Cat. No. **91CH3038-7**, 2411 (1991).

4 J. Graber, Ph.D. Dissertation, Cornell University (1993).

5 J. Graber, et al., this conference, poster Sa43.

6 J. Graber, et al., this conference, poster Sa44.

7 K. Shepard, Argonne Nat. Lab., priv. comm.

8 Q. S. Shu, et al., *IEEE Trans. Mag.*, **MAG-25**, 1868 (1985).

9 P. Schmueser, et al., **SRF 921117-10** (1992).

10 Ph. Niedermann, Ph.D. Thesis No. 2197, U. of Geneva (1986).