High Peak Power Processing of Superconducting Cavities

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Abstract

While heat treatment is beneficial in reducing the number of emitters present on the surface, we find that RF processing, especially in the presence of He gas is effective in further reducing emission. Our studies show that the benefits of processing at a fixed RF power level diminish after a short period, but further gains are possible as the RF power is increased. For continued exploration with this approach we have installed a 3 GHz pulsed high power RF source with the capability to provide 2.5 msec wide pulses of 200 Kwatt peak power at a repetition rate of 1 Hz. For this source, the Klystron is equipped with a mod anode which will permit a variable pulse length to study the effect of increasing the cavity fields very rapidly. The klystron has been operated at full emission current and full voltage. RF tests have started and the peak RF power from the klystron has been raised to 50 Kwatts.

A cold test set-up for 3 GHz Nb cavities with high power input coupler is designed, modeled for RF properties, and constructed. The input coupling can be varied from an external Q of 10^5 to 10^{10} without breaking the vacuum. In the strong coupling extreme, 200 Kwatt peak power provides the capability to raise the peak surface field to 70 MV/m within a 10 µsec (1 cell) cavity fill time. Higher fields can be reached with longer fill times at reduced coupling, depending on the progress of processing. After completion of high power processing, it will be possible to withdraw the coupling to a Q_{ext} of 10^{10} to evaluate whether the ensuing benefits will allow a high field with the standard low RF power source and a long fill time. It is planned to present the first results of low power and high power RF tests with this system.

Introduction

Currently the main difficulty standing in the way of use of superconducting Nb RF cavities in a TeV linear collider is field emission limiting of accelerating gradient. Generally the gradients are limited to 20 MV/m or less by the field emission loading, whereas gradients of at least 30 MV/m are generally believed to be the minimum requirement for economic feasibility.

Several techniques are currently in use to remove field emission as a barrier to higher gradients. The most important consideration is surface cleanliness. Special care is taken to eliminate both chemical residue and dust particles. Use of clean room techniques have greatly reduced surface contamination in the cavities.

Another important technique is vacuum firing of the cavity surface in order to remove emitter sites. Results of firing are documented elsewhere(1). This technique has been very successful; when used along with RF processing it has produced gradients on average of 20-25 MV/m in one cell cavities at LNS Cornell. This technique has its limitation in that it is not an "in situ" treatment of accelerating structures.

The technique of interest in this report is RF processing. This effect is employed as soon as fields are introduced to the cavity, whereby the field emission threshhold is initially low but through operation in the field emission regime it may be systematically increased. It is thought that drawing the emission current from the emitting sites can change and eventually destroy these sites. As power is increased, "larger" emitters will be processed in this manner.

The processing is enhanced by the introduction to the cavity of a partial pressure of helium gas (normally approximately 10^{-5} torr). The field emitted electrons ionize the helium atoms which in turn bombard the emitting sites. As the power (and thus the field level) is increased the energy with which the helium ions bombard the sites increases, again allowing for removal of "larger" sites. Neither processing with or without helium are well understood presently.

The important aspect of both types of processing is that as the power is increased the emission threshhold also increases. Presently in most cases, the threshhold is still increasing when maximum input power is reached. Therefore the next logical step is to further increase available power.

High Power RF Processing Apparatus

Following this direction, we have acquired an X3033 Klystron amplifier. The specifics of operation have been detailed elsewhere(2). The Klystron/RF amplifier circuit is shown in Figure 1. The important characteristics are:

Frequency = 3 GHz
Peak Power = 200 Kwatts
Repetition Rate = ~ 1 Hz
Average Power = 1 Kwatt
Max Pulse Width = 2.5 msec

A special cavity has been designed and constructed for use with this power source. It has E_{peak}/E_{acc} ~ 2 and a cell to cell coupling of ~ 2 %. One cell and three cell structures are to be built and tested. The starting RRR (Residual Resistance Ratio) was approximately 300, and after solid state gettering it approached RRR = 500.

A low temperature test stand has been built and tested. It is shown in Figure 2. The desired design characteristics were: 1) $Q_{external}$ variable between 10^5 and 10^{10} so that processing and low power testing could be done on the same stand without breaking the vacuum, 2) pass bandwidth of ~ 100 MHz so as not to limit the range of cavity frequencies, and 3) low static heat loss so that liquid helium loss was kept to a minimum. Tests show that all specifics have been met(3).

The variable coupling is achieved in a coaxial section. A copper plated stainless steel bellows is used as a portion of the outer conductor. This bellows allows for approximately 1.75" in vertical movement of the cavity, while the input probe remains fixed. An additional characteristic of this system is the inverted arrangement, whereby the cavity is positioned above the moving parts. In this way, particles dislodged by any movements fall away from the cavity eliminating this as a source of contamination. This also allows for cooling of the probe tip by superfluid helium which rises up the center conductor.

The RF modelled characteristics which provide the ≥ 100 MHz pass bandwidth are dominated by two areas: 1) the transition from rectangular waveguide to rigid coaxial line and 2) the ceramic coaxial window separating the waveguide and cavity vacuum systems. The transition from waveguide to coax line is necessary because the output of the Klystron is in standard WR284 waveguide, while the coupling region is a rigid 1 5/8" coaxial line. The transition was achieved through the use of a two step "doorknob" type transition. The coaxial window is necessary to isolate the ultra high vacuum required for the cavity environment from the lower vacuum of the waveguide. It was matched with quarter wave transformer sections.

Initial Tests: Cavities S3C1-2 and S3C1-1

The initial tests were made using cavity S3C1-2. The cavity had frequency = 2980 MHz, and low power Q_0 ~ 10^9 at 1.8°K. As the incident power was increased, field emission began to appear (evidenced by x-ray detection near the test stand). At maximum, dissipated power was 12.4 Watts, E_{peak} was 18.9 MV/m, and the cavity Q_0 had decreased to 2 x 10^8. This limit was reached on successive days, and attempted processing at this power level was not removing the emission. This stability of the emission indicated that it would be a good candidate for high power processing.

The klystron waveguide was then attached to the stand, and the coupling increased such that $Q_{ext} \sim 10^6$. The cavity was then processed with approximately 200 pulses with peak power = 50 Kwatt, pulse length = 100 µsec. Transmitted power levels during these pulses indicate that the field level consistently reached approximately 33.5 MV/m. X-rays were coincidental with many of these pulses, indicating emission. The transmitted pulse shape was rather inconsistent, at times showing a breakdown type behavior. This will need further investigation.

The low power source was then reconnected, and coupling drawn back such that $Q_{ext} \sim 10^9$ ($\beta \sim 1$), and the initial tests repeated. On increase of incident power the cavity did not show the degradation of Q_0 (brought on by field emission loading) which was present prior to processing. In addition, the X-ray signal diminished to almost zero. Unfortunately, the cavity itself limited the tests, as thermal breakdown was encountered at a field level of 19.4 MV/m. (A possible source of this was a repaired weld hole in the cavity.) The dissipated power at this field level was ~ 3.26 W, and the Q_0 had only decreased to 8×10^8. A comparison of the Q_0 vs. E_{peak} behavior before and after high power processing are shown in Figure 3.

Cavity S3C1-1 was attached to the test stand and tested in the same manner. Results of this test were similar to those of S3C1-2. Prior to high power processing, field levels were limited by available power to E_{peak} = 23.2 MV/m. At this field level, P_{diss} = 10.21 Watts and $Q_0 = 3.57 \times 10^8$. Heavy field emission was indicated by X-ray detection. This was not removed by extended low power (10 W power dissipation) processing, therefore the high power system was attached.

High power processing was performed with the following characteristics:

Peak power	=	40 kWatt
Pulse length	=	600 µsec
Q_{ext}	~	2×10^6
# of pulses	=	1500
Maximum E_{peak}	=	49.3 MV/m

The coupler was then withdrawn and the low power source reconnected. Like cavity S3C1-2, the maximum field was limited by thermal breakdown. The maximum field reached was E_{peak} = 25.7 MV/m, with P_{diss} = 7.4 Watts and $Q_0 = 5.98 \times 10^8$. The amount of field emission (as indicated by X-ray detection) was lowered, as with S3C1-2, but the effect was not as dramatic. Plots of Q_0 vs. E_{peak} for the cavity before and after high power processing are shown in Figure 4.

Remarks

The initial tests are very encouraging for the future application of this technique as a means of eliminating field emission. While the peak field levels reached are not as high as previously reached by already existing methods, both cavities tested showed improvement after high power processing in situations where low power cw processing had been ineffective.

In addition, the initial results have shown that in both cavities the short pulse, maximum field level was nearly twice the field level which induced thermal breakdown when operated cw. Previous results from high power processing(4) have indicated this effect. This effect will be investigated further.

REFERENCES

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(3) J. Graber, M.S. Thesis, Cornell Univ., to be published.

(4) I.E. Campisi et.al., IEEE Transactions on Nuclear Science, Vol. NS-30, No.4(August 1983).

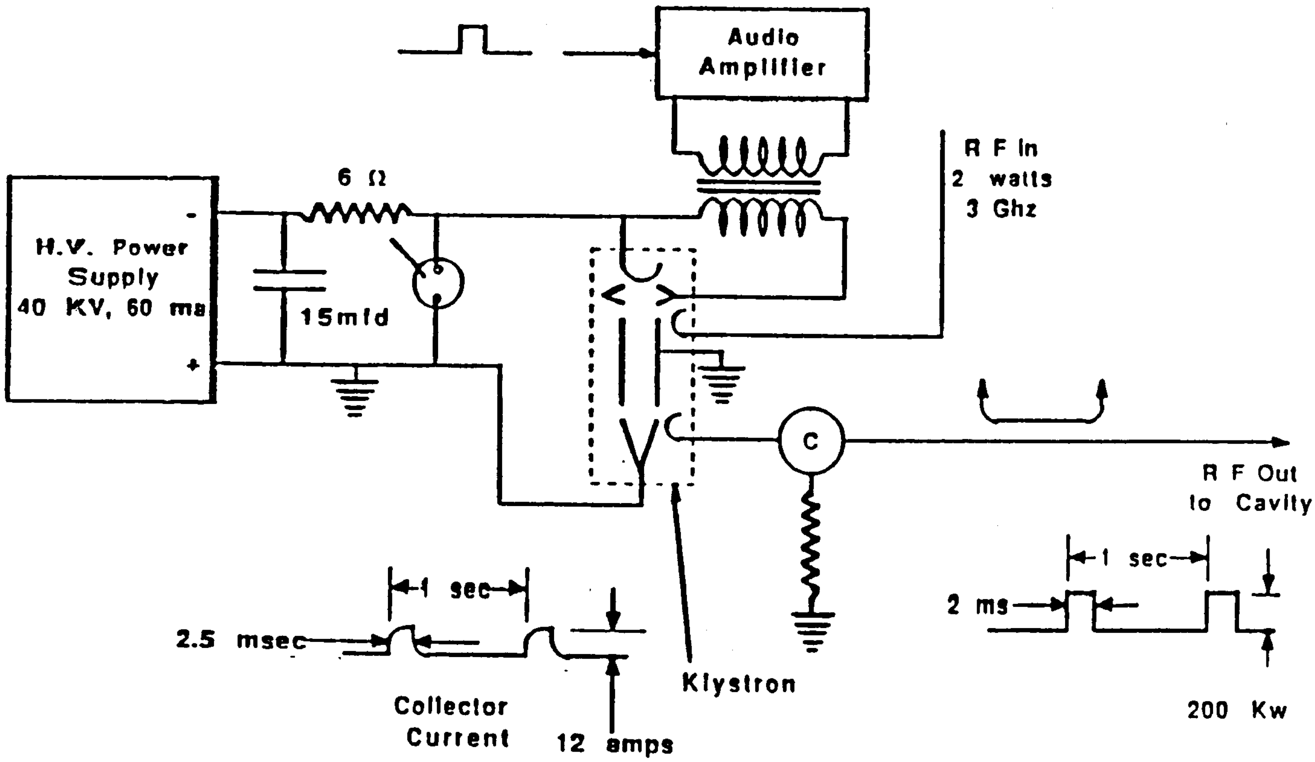

Figure 1. Klystron/RF Amplifier circuit used in HPP experiments.

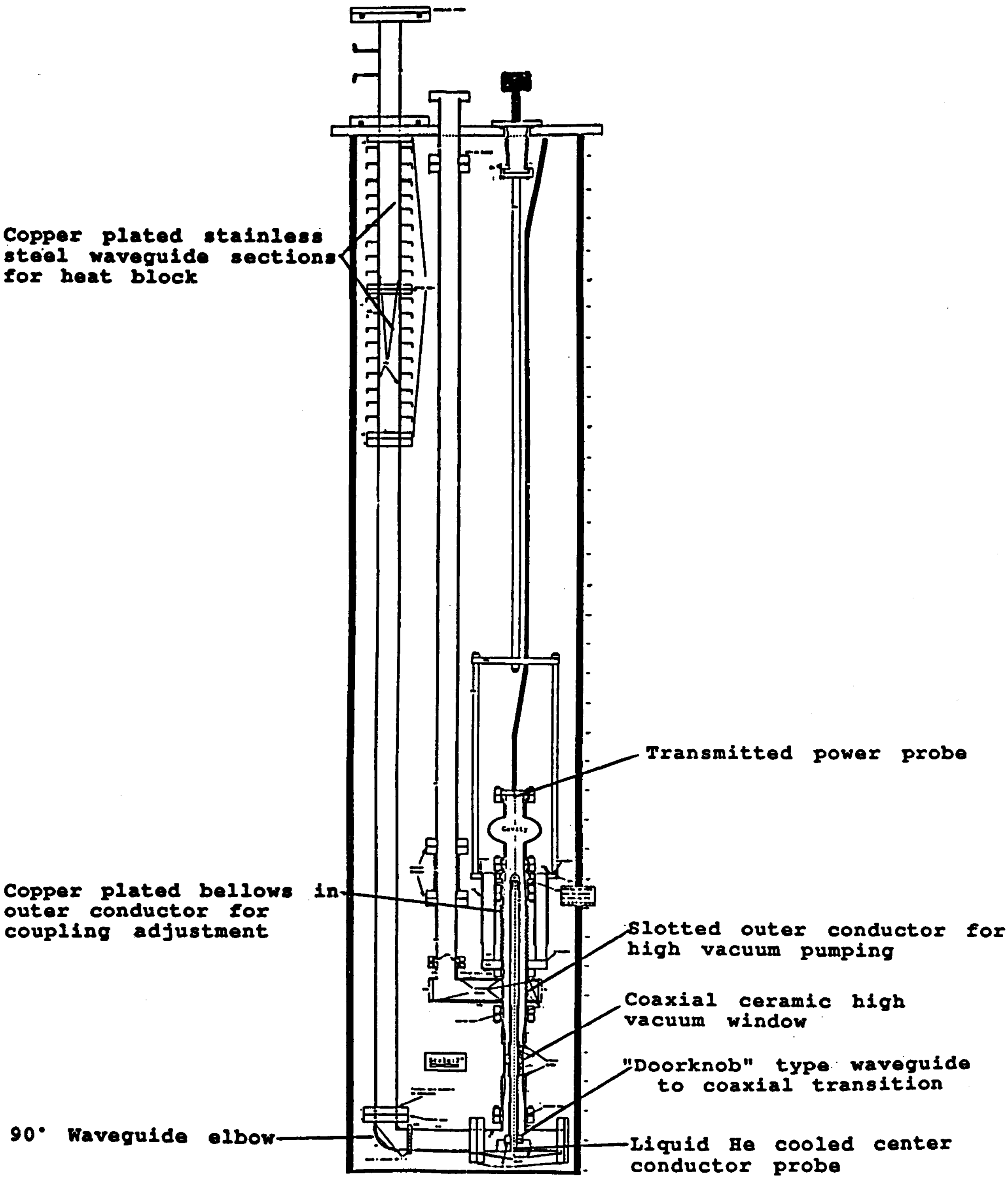

Figure 2. High peak power experimental test stand.

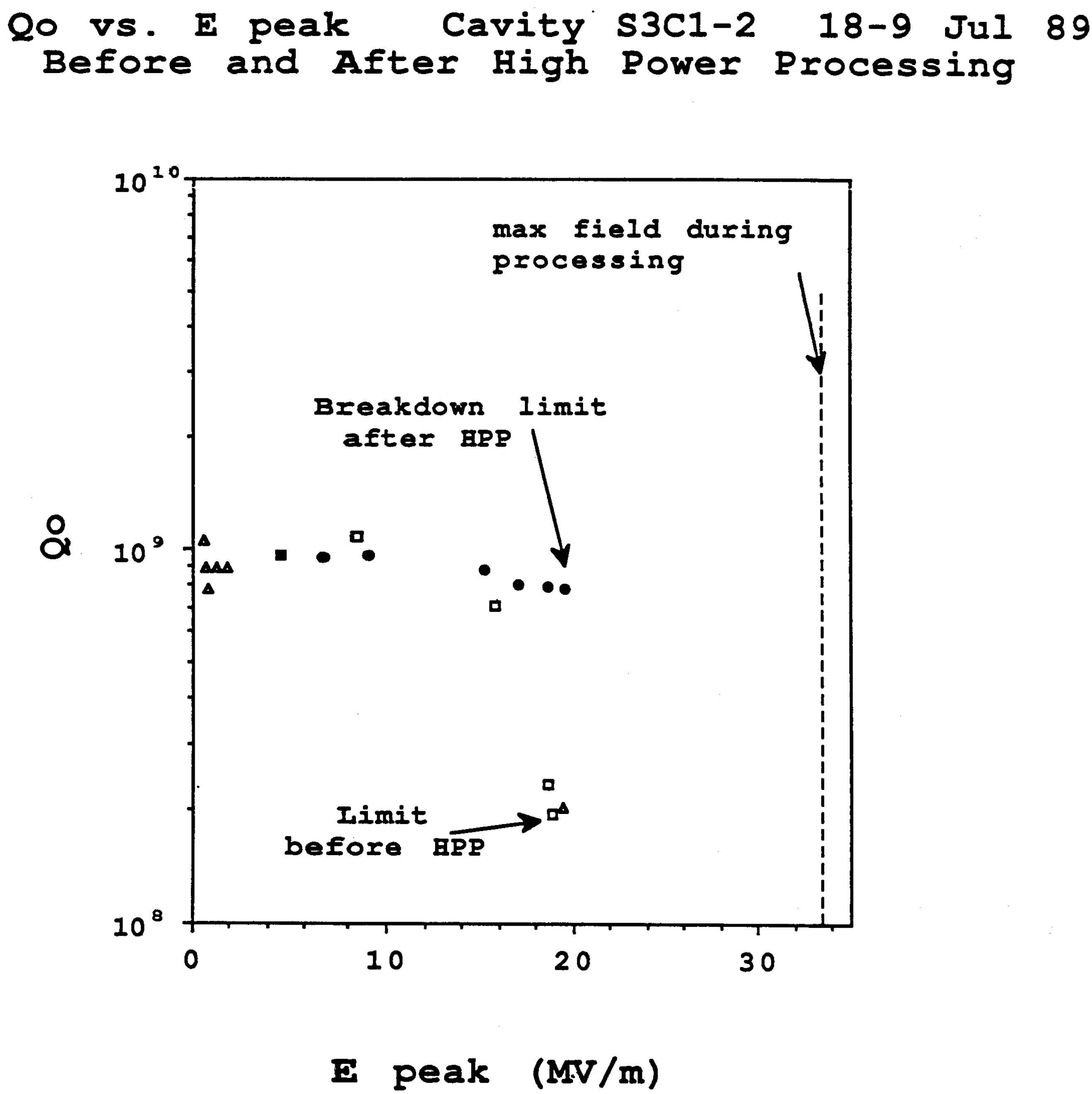

Figure 3. Qo vs. Epeak plots for cavity S3C1-2, before and after *high peak power* processing.

Qo vs. E peak Cavity S3C1-1 1-2 Aug 89
Before and After High Power Processing

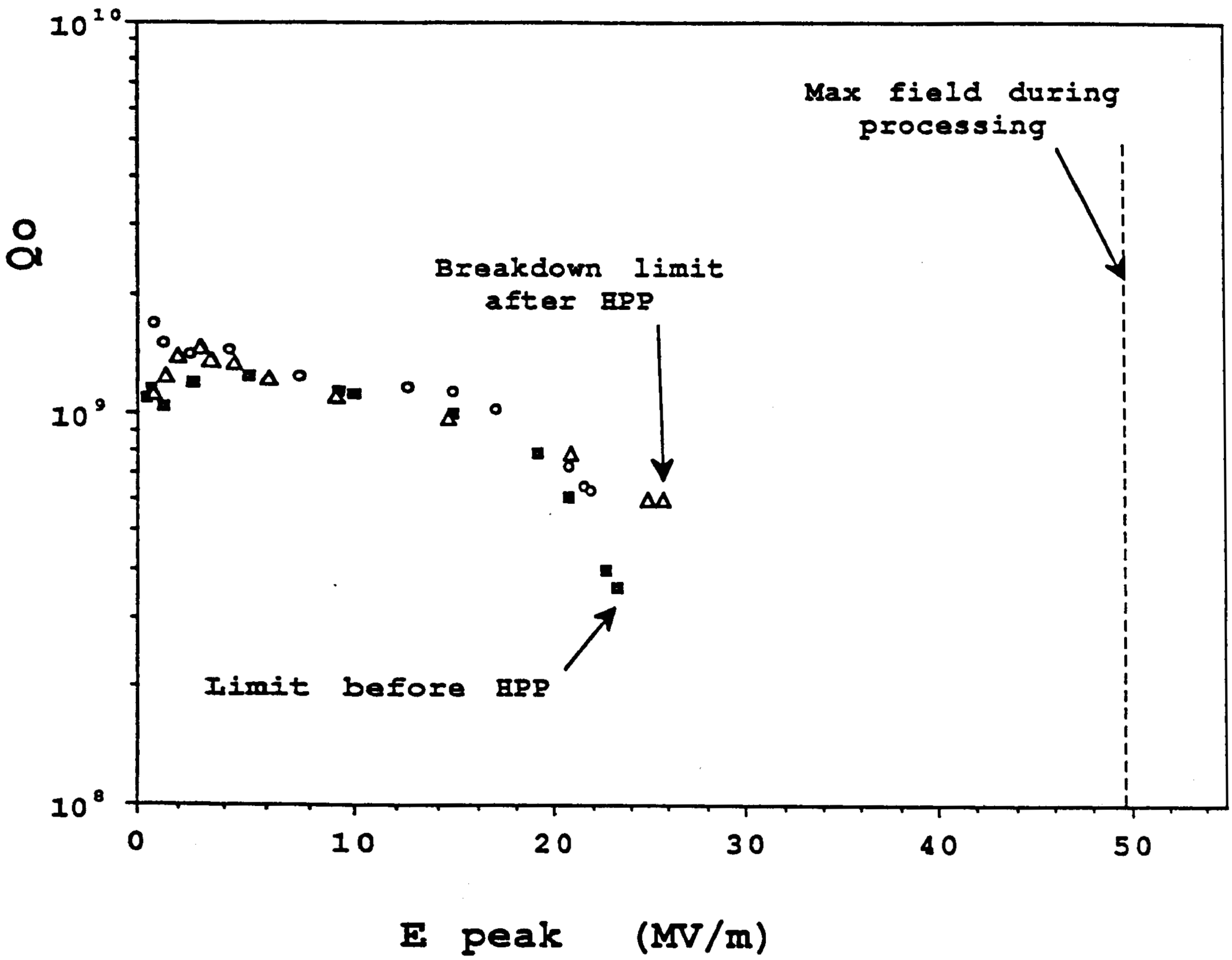

Figure 4. Qo vs. Epeak plots for cavity S3C1-1, before and after *high peak power* processing.