In Situ Recovery of a Superconducting Cavity from Contamination due to Vacuum Failures

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Abstract

A nine-cell 3 GHz niobium cavity was accidentally exposed to the roughing vacuum of the helium bath pumping line while immersed in liquid helium. After the incident, the cavity was pumped down to 10^{-6} mbar while cold and the quality factor reduction in Q of about a factor of three was observed at low field. The first data on Q versus the electric field showed a strong field emission. After high-power processing, however, the cavity achieved higher Q and a maximum accelerating field value of 18 MV/m. The cavity was then warmed up to room temperature and pumped for about a week, heating it up several times to 50° C to remove condensed water. During the pumping at room temperature, a power failure occured with the consequence that the cavity was exposed to dirty room air at atmospheric pressure. The finally achieved pressure at 300 K was $6\ 10^{-8}$ mbar. In the following cryogenic test the previous good performance was recovered after high power processing.

The cavity was kept evacuated (< 10^{-7} mbar) at room temperature for a period of three months. In the most recent test a Q of $2\ 10^{10}$ was achieved at low fields, dropping to $7\ 10^{9}$ at an accelerating field of 16 MV/m. Then a deliberate vacuum accident was made. With the cavity immersed in superfluid helium, a needle valve to 1 atmosphere was opened for 20 seconds, leading unfiltered air into the cavity. In addition the air contained in the vented flexible hose of a turbo-pump was admitted to the cavity. After evacuating the cavity while at liquid helium temperature, the cavity was tested to ensure that the Q and field had degraded from the accident. Then the cavity was warmed up, pumped out and cooled down again. Field emission was substantial, but a good recovery from the contamination was achieved, especially after high-power processing (HPP).

1 History of cavity

The nine-cell cavity S3C9-5 was fabricated in February 1992. The RRR of the starting material was 250-300. The half cells were yttrified to improve the RRR to roughly 500-600. The first test was Q limited because of hydrogen contamination during chemistry (the Q disease). After firing at 900° C for 2 hours, the second test was limited by field emission which was processed with HPP, but eventually by thermal breakdown at Eacc = 10 MV/m. Another chemical and heat treatment followed (30 min nitric acid, 10 min BCP and 2 hours at 900° C). The third test (see Fig. 1) was initially characterized by strong field emission. After high power processing (HPP), the accelerating field raised to13 MV/m. A room temperature cycle followed without opening the cavity vacuum. The fourth test yielded E_{acc}=14 MV/m but indicated problems with the transmitted-power probe. The system was then warmed to room temperature and an electrical short in the probe was removed. The cavity was etched in nitric acid for 30 minutes and chemically polished in 1:1:2 BCP for twice 1.5 minutes. No heat treatment followed. The quality factor at 1.4 K and low field levels showed a remarkable increase, from $6\ 10^{9}$ to $2\ 10^{10}$.

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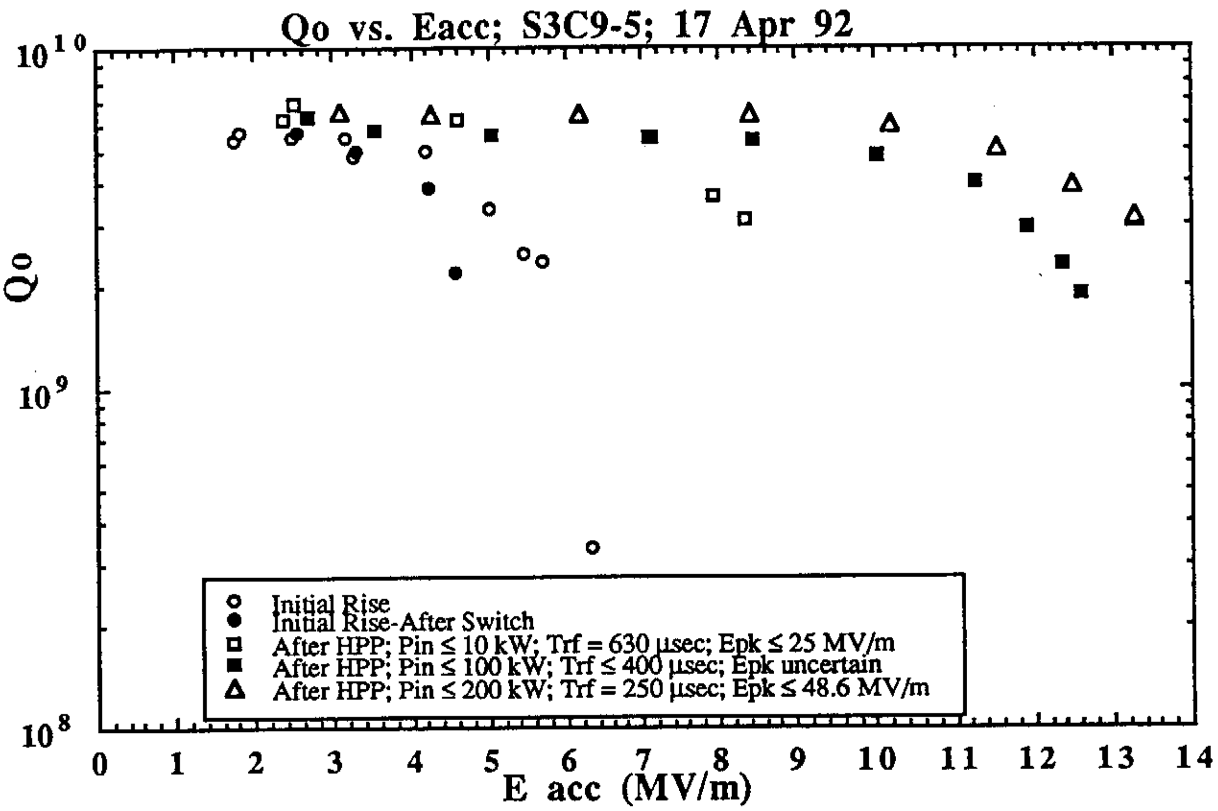

Fig. 1: Typical example of field emission removal by high power processing (HPP)

2 First vacuum accident and recovery

The interior of the cavity was accidentally exposed to the roughing vacuum of the helium bath pump-out line while already immersed in liquid helium. The pressure in the cold cavity rose to at least a few mbar. Nevertheless it was decided to continue the test to investigate the possibility of recovering the cavity without warming it up. A turbo pump was installed to aid the ion getter pump in evacuating the cavity. Radio frequency power was put in at a pressure of about 10^{-6} mbar (more than two orders of magnitude worse than usual). The quality factor degraded from $3x10^{10}$ to $1x10^{10}$.

The first attempt to reach higher gradients resulted in a rapid decrease of Q (open circles in Fig.2) and a pressure rise in the cavity. High peak power processing with instantaneous power up to 100 kW improved the cavity performance considerably. The final Q versus E curve (Fig.2) shows an almost constant Q value of more then 10^{10} up to an accelerating field of 12 MV/m. At a Q value of 4x 10^9, as envisaged for a linear accelerator, the accelerating field is about 18 MV/m. This is the second-best result of all nine-cell 3 GHz cavities tested so far and clearly demonstrates that the cavity has completely recovered from the vacuum breakdown.

The cavity was then allowed to warm up to room temperature. While in this state, the cavity pressure accidentally rose to 1 bar due to a failure of a turbo pump. 1 atmosphere of dirty room air was admitted into the warm cavity, but immediately pumped out.

The cavity was pumped down to 7 10^{-8} mbar, cooled to 1.5 K and re-tested. Field emission was again heavy. Some recovery was achieved with low power processing. Full recovery was achieved by applying high power processing with 100 kW peak power, corresponding to a peak field of 58 MV/m at the superconductor surface (see Fig.3).

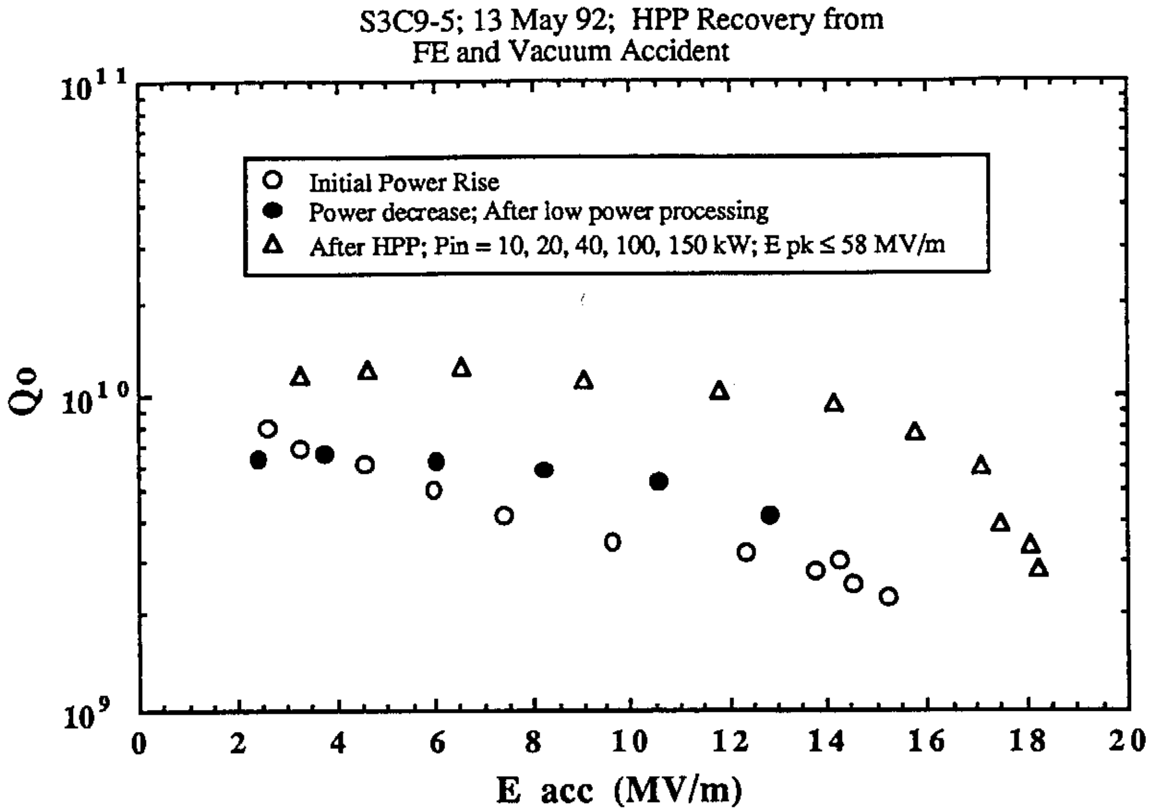

Figure 2: Recovery from cold vacuum accident with HPP

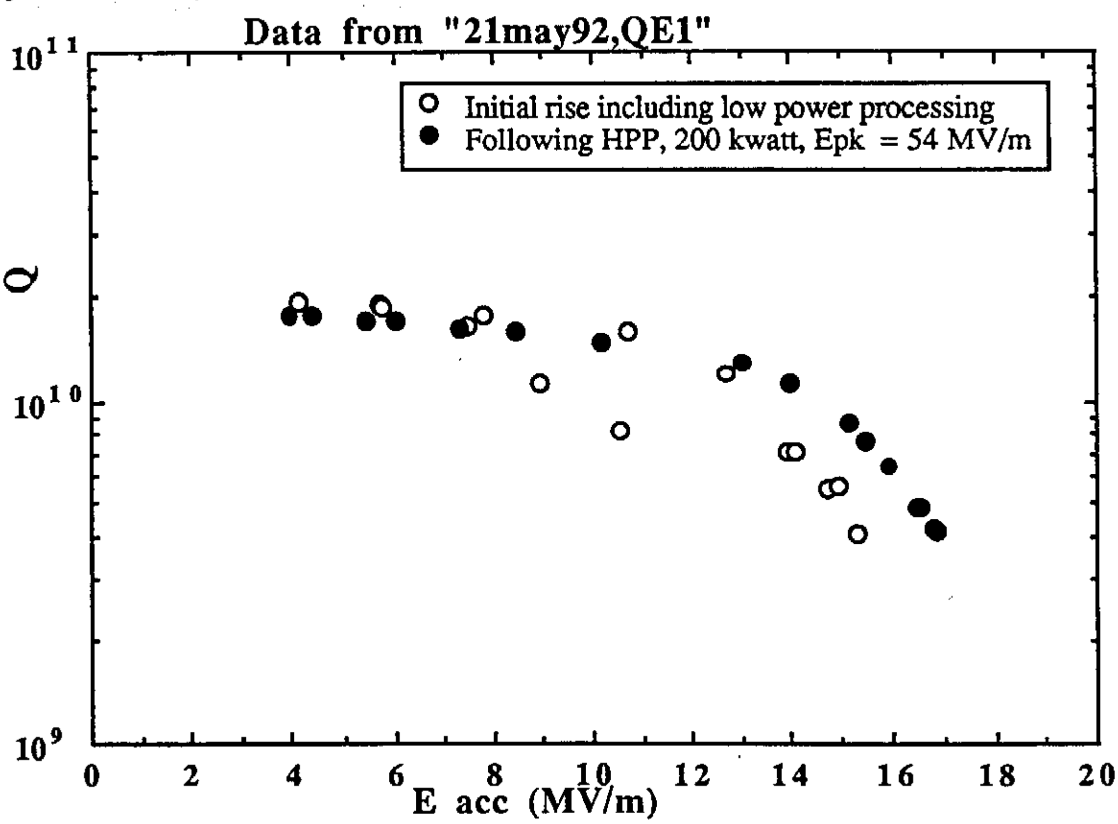

Fig 3: Recovery with HPP from a warm vacuum accident to 1 atm of dirty air

3 Deliberate vacuum accident

After the vacuum accidents and the largely successful attempts to recover the performance, the cavity was kept on the test stand for more than three months at a vacuum of < 10^{-7} mbar at room temperature. The most recent test was designed to provoke a really severe vacuum accident with dirty, unfiltered air entering the cold cavity and possibly oil remnants from a vented turbo-pump station. Before exposing the cavity to this severe contamination a Q versus E curve was measured (Fig.4). A quality factor of more than 10^{10} was achieved up to E_{acc} = 15 MV/m.

A needle valve to 1 atmosphere was opened for about 20 seconds leading unfiltered air into the cavity vacuum system. Then the 2 m long flexible hose of a vented turbo-pumpstand was also opened to the cavity vacuum to simulate the effect of a turbo-pump failure.

Without warming up, the cavity was pumped initially with the turbo pump and after 15 minutes (pressure < 10^{-6} mbar) with an additional ion getter pump. The following test measurement revealed a noticeable degradation, both in Q and in the maximum field (see Fig.4), but after some processing with a 20 W travelling wave tube amplifier a respectable performance was achieved, considering the severity of the incident.

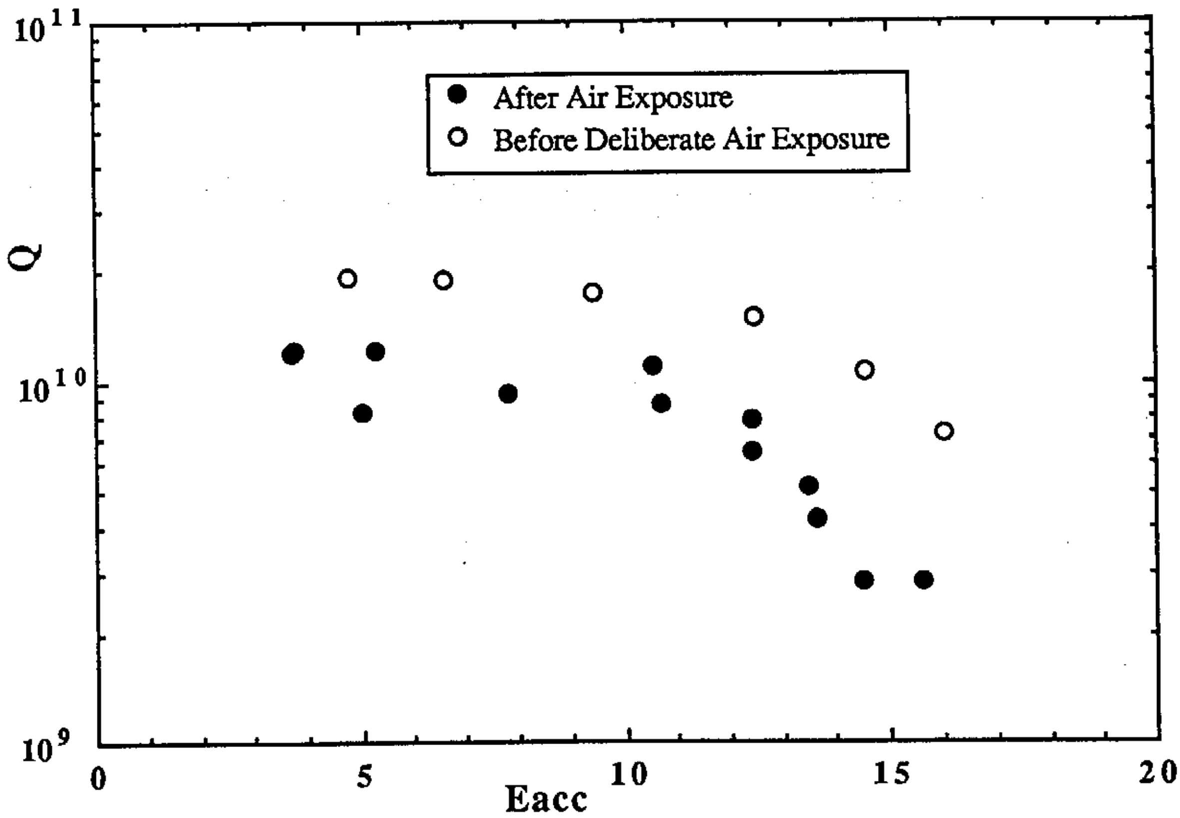

Fig.4: Effect of deliberate cold vacuum accident

Unfortunately it was not possible at this moment to continue with high-power processing because of problems with the liquid helium system which required warming up of the cryostat to room temperature.

The pressure in the cavity rose to 9 mbar at 300 K. The cavity vacuum system was then pumped for 10 days at 300 K. After cooldown to 1.4 K, Q was again measured as a function of field and then high-power processing was done. Fig.5 summarizes the cavity performance before any processing, after low-power processing and after high-power processing up to a power level of 150 kW . The quality factor at low power amounts to 1.2 10^{10}, so there is a certain permanent degradation (which could probably be overcome by demounting and re-etching the cavity) The field emssion was much more intense, suggesting the influence of gases released during warm up activating new sites.

The really remarkable observation is, however, that the good high-field properties of this cavity were recovered by the high-power processing

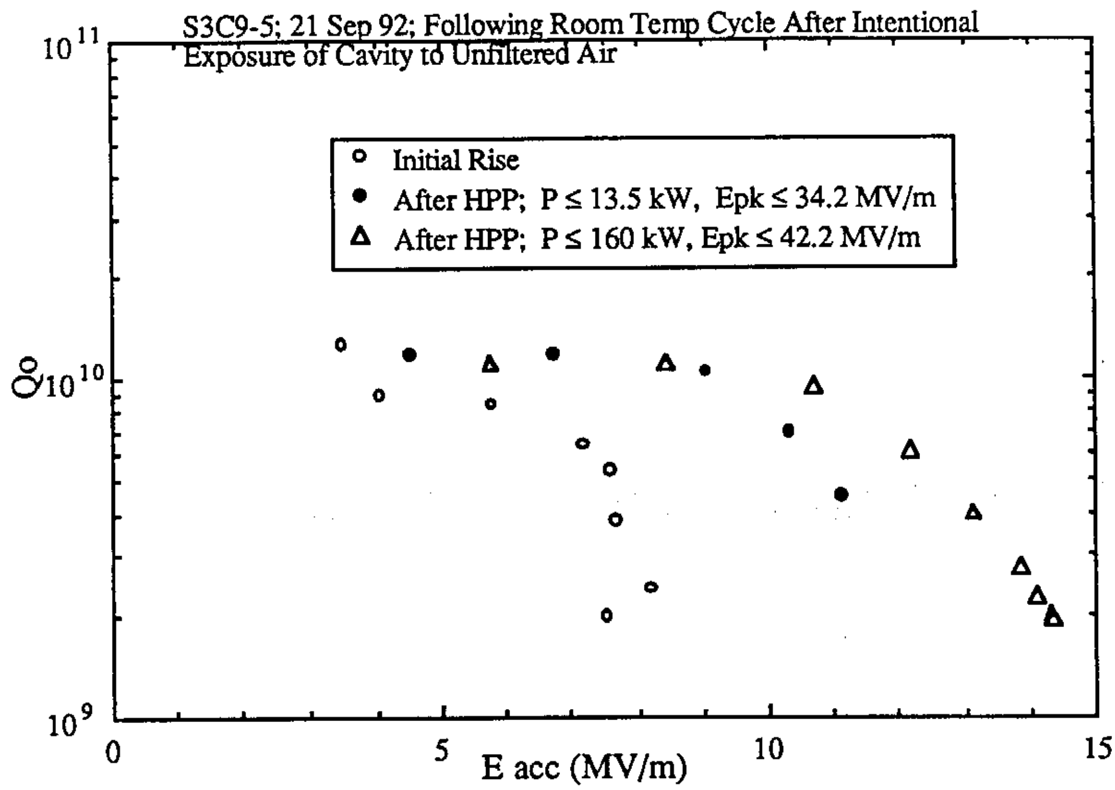

Fig.5: Recovery after room temperature cycle

4 Conclusions

In the course of commissioning and operating any superconducting RF accelerating section, the ultra high vacuum of the cavities may be exposed to varying degrees of contamination due to power failures, problems with the vacuum system or fracture of rf windows. It has been demonstrated that for different types of such incidents, two at cryogenic, one at room temperature, high power processing can be successfully applied to fully recover the operating field levels in situ. Significant amounts of accelerator operating time could be saved in cases of vacuum failures by providing for HPP capability in the tunnel.

Finally these experiments show the value of the HPP technique to process away emitters introduced during final assembly of the cavity, when dirt is sometimes admitted while attaching couplers.