Status and Outlook for High Power Processing of 1.3 GHz TESLA Multicell Cavities,*

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SUMMARY

In order to increase the usable accelerating gradient in Superconducting TESLA cavities, the field emission threshold barrier must be raised. As has been previously demonstrated on S-Band cavities, a way to accomplish this is with the use of high peak power RF processing. A transmitter with a peak power of 2 Mwatt and 300 μsec pulse length has been assembled and has been used to process TESLA cavities. Several five cell TESLA cavities at 1.3 GHz have been manufactured for this purpose. This transmitter and the cavities will be described and the results of the tests will be presented.

INTRODUCTION

High pulsed power processing (HPP) has been proved to be an effective method to overcome field emission in SC cavities. Many experiments done with 1-cell, 2-cell and 9-cell cavities at 3 GHz are discussed in other papers at this conference. The salient results of these experiments are:

1) Accelerating fields between 15-20 MV/m were reached with two 9-cell cavities (3 GHz) in 7 consecutive tests. For each test the surface of the cavity was prepared anew. In each case, heavy field emission was successfully processed with HPP to reach the final field levels. The low power Q was undamaged from HPP, so damage is not a concern.

2) The effectiveness of the processing depends clearly on the highest surface electric field reached during the pulsed processing stage. The highest pulsed surface field reached was 72 MV/m for a 1-cell, and 60 MV/m for a 9-cell. Power levels up to 50 kwatts were used for 1-cells and up to 200 kwatts for 9-cells.

3) In 9-cell cavities, field emission was completely eliminated for field levels up to $E_{cw} = 0.5\ E_{pulsed}$. If field emission is tolerated till the Q falls to about 5×10^9, then higher fields can be reached, typically : $E_{cw} = 0.60\ E_{pulsed}$.

4) Processing takes place by an explosive mechanism. Dissection of processed cavities shows 1 - 10 μm size molten craters with traces of the original contaminants responsible for the field emission.

5) The processing is effective against new field emission when additional contaminants are introduced, such as by vacuum accidents.

6) During processing the Q falls to between 10^7 and 10^6.

7) It is possible, during pulsed operation, to exceed the field at which cw thermal breakdown is encountered; but then there is a strong competetion for the applied high power between field emission losses for processing and the growth of the normal conducting region(s). The method is, therefore, ultimately limited by breakdown, initiated by the maximum surface magnetic field. A low H_{pk}/E_{acc} ratio and a high RRR are, therefore, advised.

8) In a special 2-cell cavity with reduced magnetic surface field, it was possible to reach a surface electric field of 113 MV/m pulsed, and 100 MV/m cw, corresponding to a world record accelerating field of 34.6 MV/m.

EQUIPMENT FOR HPP AT 1.3 GHZ TESLA CAVITIES

Needed Power

For TESLA, the RF frequency chosen is 1.3 GHz, and the structure is a 9-cell with length 1.038 meters and $E_{pk}/E_{acc} = 2.1$. It is desired to eventually reach 25 MV/m accelerating, or $E_{pk} = 53$ MV/m at a Q of 5×10^9. To determine the peak power we need to apply, we are guided by the results from our 3 GHz HPP experiments. If we can expect, $E_{cw} = 0.6\ E_{pulsed}$ after HPP, with some field emision still present, we need to be prepared to reach more than 90 MV/m surface field pulsed. We must also be prepared for the Q_o to fall to 2×10^6 during HPP. The pulse length over which the field can be built up during the pulse is a very important parameter in assessing the power. Fig. 1 shows that the needed peak surface field can be reached with 1 Mwatt of power and pulse length of 1 msec.

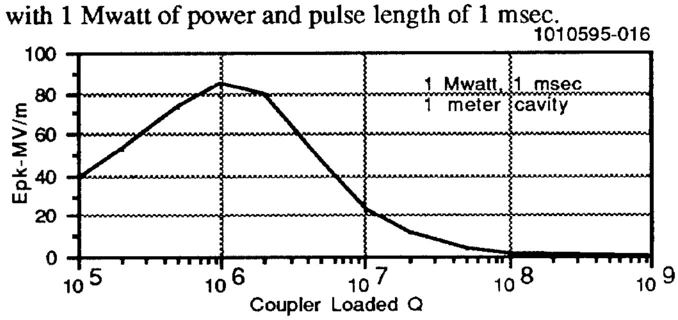

Fig. 1.

Klystron and Modulator

While preparations are proceeding for installation of SRF infrastructure and a TESLA TEST FACILITY at DESY, a

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program has been launched at Cornell to test HPP at 1.3 GHz as soon as possible. The Boeing Defense and Space Group kindly agreed to lend us a klystron (Thompson TH2104) and PFN modulator. The system is intrinsically capable of 10 MWatts peak at 200 μsec with 185 Kvolts, or 5 Mwatts at 300 μsec. With commercial constant charge, constant current regulated pulsed capacitor charging supplies, we were successful in providing 110 KV to the klystron to obtain uniform 200 μsec long pulses of 2 MWatt peak power. The klystron and modulator system as installed at Cornell are shown in Fig. 2.

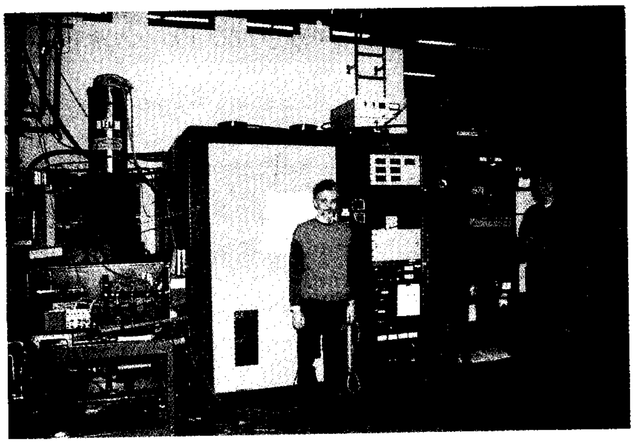

Fig. 2.

Niobium cavities

We decided to fabricate and test 5-cell structures instead of the final 9-cell structures for two important reasons: a) The available klystron/modulator operates at a maximum pulse length of 300 μsecs, b) The existing SRF facilities at Cornell (chemical treatment, shielded cold test area, furnace, clean rooms, etc.) are not of the appropriate size to handle a 1 meter long cavity. Fig. 3 shows the expected peak field that can be reached with 1 Mwatt of power and a 5-cell cavity at the available pulse length.

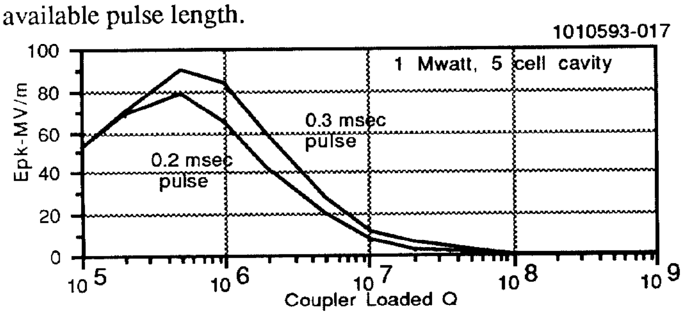

Fig. 3

Two 5-cell Nb cavities of the TESLA shape were built at Cornell. The accelerating mode properties of the cavity are listed in Table 1

Frequency	1308 MHz
R/Q	1088 Ω/m
E_p/E_{acc}	2.1
H_p/E_{acc}	42 Oe/MV/m

Table 1.

The cells are polarized as shown in Fig. 4 so that eventually a single HOM coupler can damp both polarizations of dipole higher order modes. The measured splitting for the dominant dipole modes was 13 MHz (TE_{111}) and 50 MHz (TM_{110}) modes. Fig. 5 shows a complete structure installed in the chemical treatment facility. One 2-cell and two 1-cell Nb cavities were also built. The RRR of the Nb used to fabricate these cavities was between 250 and 300. Copper cavites were also built to test the dies and fixtures.

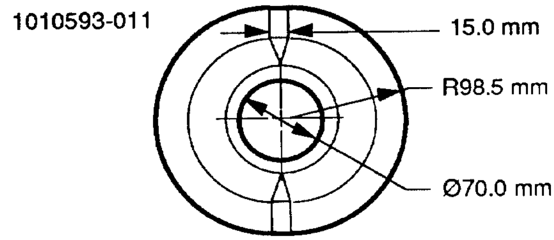

Fig. 4

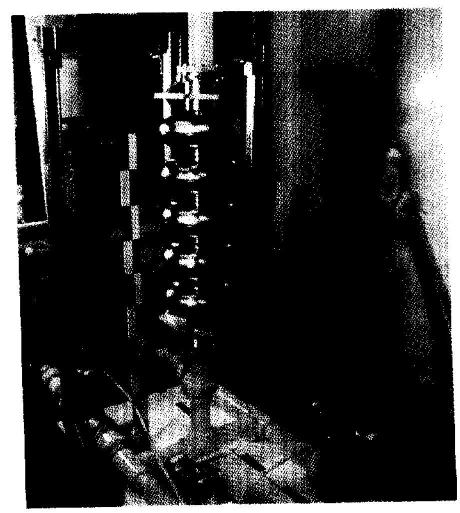

Fig. 5

1.3 GHz HPP Test Set Up

A high power cold test set up shown in Fig. 6 was built. The high power enters the cryostat top plate (not shown) through a WR650 reduced height waveguide. A room temperature teflon window above the top plate allows a vacuum in the waveguide. Near the bottom of the cryostat is a waveguide to coax doorknob transition, with an integrated cylindrical ceramic window to isolate the high vacuum, cavity region. The window was coated with TiN to reduce the secondary emisison coefficient. After fabrication, the VSWR of the input coupler was less than 1.6 between 1280 and 1320 MHz. The penetration of the antenna into the cavity is adjustable by a copper plated hydroformed bellow in the outer conductor. Q_{ext} can be changed from 10^5 to 10^{10} with 4" of travel. The slotted region of the outer conductor just above the doorknob is connected to the cavity vacuum pumping line. To check the microwave performance of the coupler, the BCS Q at 4.2 K of a 1.3 GHz Nb cavity was measured and verified for different positions of the antenna.

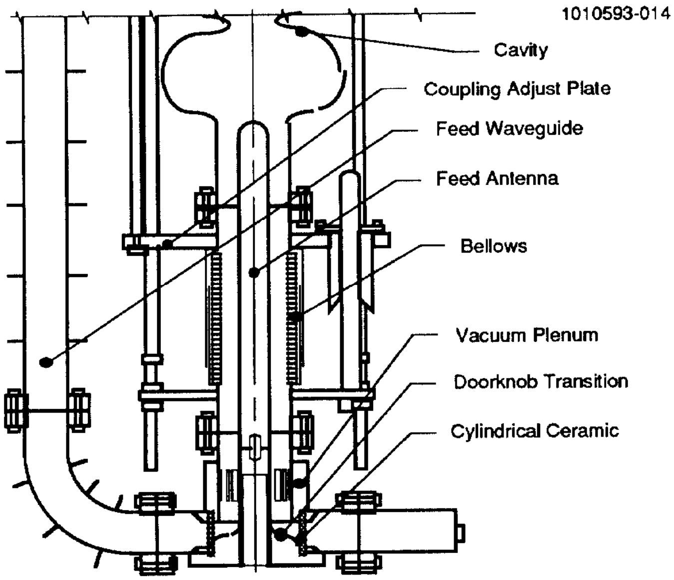

Fig.6

COLD TEST RESULTS

One problem is that the top of a 5-cell cavity stands at about 70% of the useable liquid helium reservoir height. Even with several batch fill and pump down iterations, it was difficult to keep the cavity completely under liquid at 2 K. A good solution to this problem was to pump down a 500 litre storage dewar to 2.2 K and then transfer 2.2 K liquid across into the test cryostat. By this method the running time at 2 K could be extended by many hours. While this solution was still being developed, it was decided to test the HPP method with the 2-cell cavity.

Fig. 7 shows three Q vs E curves for the test of the 2-cell cavity

a) The initial cw test with low power

b) after conditioning with cw low power only

c) after HPP up to 320 kwatts, 200 msec, maximum field 67 MV/m.

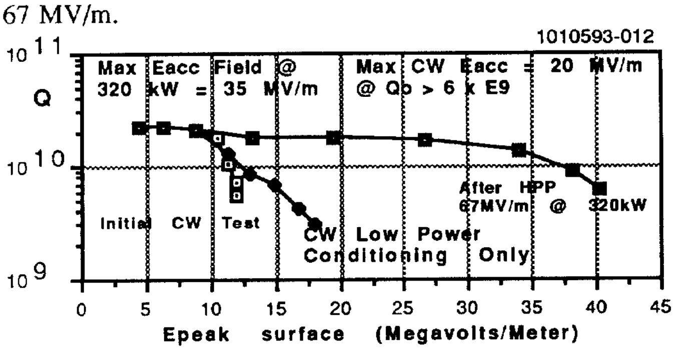

Fig.7

During pulsed power application, the maximum peak surface electric field reached was 67 MV/m.

The 2-cell result confirms many of the aspects of HPP that were proved in the 3 GHz program. Field emission was successfully processed away without damaging the low power Q. The maximum field reached during the pulsed stage shows, as expected, that the Q fell to about $2x10^6$. The predicted E_{pk} was 70 MV/m for a 2-cell cavity, on applying 320 kwatts (200 µsec) and assuming that the Q_O during processing fell to $2x10^6$. The maximum predicted field is very close to the experimental result (67 MV/m). The field level E_{CW} at which the Q from field emission drops to $6x10^9$ is 0.6 E_{pulsed}.

After the helium level problem was brought under control, a 5-cell cavity was tested. Unfortunately, due to reasons not yet understood, the preparation was not as clean as we desired. Both the low power Q and the field emission threshold were significantly lower than our usual results. Fig. 8 shows three Q vs. E curves. Although the initial field emission was heavy at 4 MV/m accelerating, with HPP we were still able to process and reach about 10 MV/m accelerating. The maximum power applied was 300 kwatts, at which power the E_{pk} reached during the pulsed stage was 40 MV/m. Again this implies that the Q fell to about $2x10^6$ during HPP. We were not able to couple more than 300 kwatts because we encountered severe breakdown in the coupler.

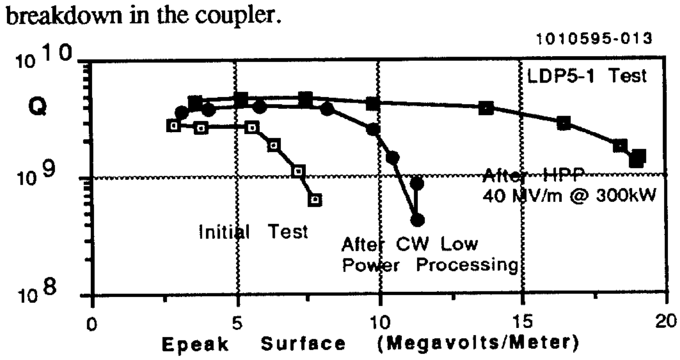

Fig.8

Two types of coupler conditioning events were seen in the 1.3 GHz HPP coupler. Between 10 and 300 kwatts the first type, called the staircase, was usually accompanied by severe vacuum degradation in the waveguide region. After some conditioning, it was possible to process this type of event, with improvement in vacuum and the return of the transmitted rf power signal to the expected exponential decay. The staircase event would restart on raising the power. Above 300 kwatt, a second type of coupler event was encountered. Nearly all the power was absorbed or reflected, so that very little power could be coupled to the cavity. Studies are in progress to determine the location of the coupler troubles. So far, the teflon window is exonerated, so the problem is originating from the cold end, i.e. the window/doorknob/coax/bellows area.

CONCLUSIONS

All the equipment necessary to test HPP at 1.3 GHz has been completed, installed and tested: 2 Mwatt klystron, 200 µsec pulse length modulator, high power test stand, and several multi-cell niobium cavities. The first test of HPP at 1.3 GHz shows that the technique works against field emission as expected, E_{acc} = 20 MV/m was reached. The processing power levels needed are as predicted from 3 GHz experiments. Understanding the limitations of the coupler is the next step to overcome the present 300 kwatt limit.