FIELD EMISSION PROCESSING OF SUPERCONDUCTING RF CAVITIES WITH HIGH PEAK POWER*

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SUMMARY

The main difficulty standing in the way of the use of Superconducting RF cavities for TeV linear colliders is that, due to field emission, accelerating gradients are generally limited to less than 20 MV/meter. One technique which is commonly used to decrease field emission has been the use of RF processing in the presence of Helium gas. In order to push this technique to yield even higher fields, a facility is being developed to process Niobium S-Band structures up to 200 Kwatt peak incident power for pulse widths up to 2 milliseconds. This system will be described and preliminary results will be reported.

INTRODUCTION

For many years the limitation on the gradient at which superconducting cavities could be operated was imposed by thermal breakdown. The hypothesis is that some defect would become hot, the resulting warm area would spread, and the superconducting surface becoming normal. This limitation was overcome, for the time being at least, with the use of high RRR material with its inherent high thermal conductivity.[1]

For the past several years, now that Niobium material with RRR > 200 is available, most laboratories can routinely reach the field emission limit.

The use of RF Superconductivity in a TeV Linear Collider would require accelerating gradients = 30 MV/meter. This number, with current cavity shape concepts, translates to = 60 MV/meter peak surface electric fields. This gradient must be achieved not only in the laboratory, but must be routine with a high degree of certainty, and must be economically feasible.

FIELD EMISSION

Several techniques have been used to increase the limit imposed on the peak electric field by field emission.

The first and perhaps most important technique employed was surface cleanliness. Steps were taken to assure that there were no particulate chemical residues left on the surfaces and modern “clean room” techniques were employed during the assembly process to eliminate all dust particles from the cavity surface.

The second technique that has been employed is the vacuum firing of the surface to remove emitter sites.[2] These techniques have certainly raised the field emission limit and have been described elsewhere. [3]

The third technique, RF processing, is employed as soon as the structures are operated above zero power levels. It is observed that the first time RF power is applied, the field emission threshold is low and immediately can start to increase. This threshold for field emission will increase only if the device is operated in the regime of field emission. Thus the power level can then be increased to again exceed the field emission threshold. The hypothesis is that “larger and larger” emitters are thermally destroyed or made inactive as the RF power is increased. This technique is used in all laboratories at least initially and in some cases is used to high power as a final treatment. [4]

A variation of this technique is helium processing. In this case a partial pressure of helium gas is introduced into the cavity and RF power is applied. The amount of gas is usually just a little less than that which would lead to glow discharge and is typically 10^{-5} torr. The RF power is then raised as a function of time, always operating to as high a level of electric field that the system will allow. An increase in the field emission threshold is usually observed. After some time the helium is removed and this increase of the threshold usually remains higher. This improvement is permanent until the surface is chemically changed in some way.

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The hypothesis is that the emitters have been destroyed by bombardment with the helium ions. The higher the power, the higher the energy of the ions and therefore the “larger” the size of the emitters that can be destroyed. The exact details of this process are not well understood.

It should be noted that in most cases the field emission threshold is still increasing when the limit of the input power capability is reached. For this reason we believe that the field emission limit might be raised by increasing the available peak RF input power.

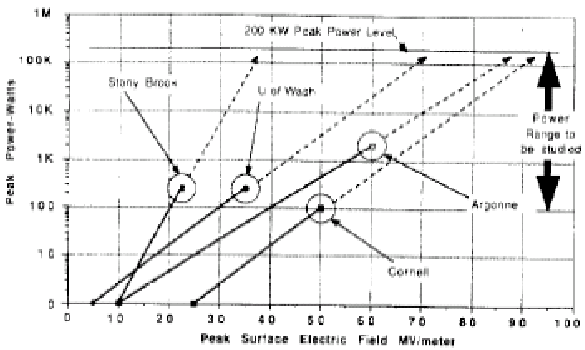

Figure 1. Representative Results Obtained with R.F.Processing at Various Laboralories on Superconducting Structures,both Lead Plated and Nioblum

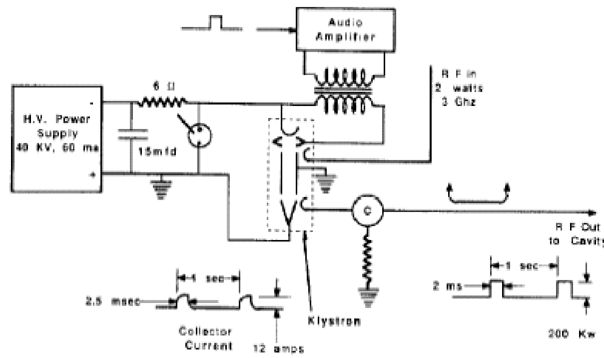

Figure 2

Figure 1 shows some typical RF processing results from various laboratories.[5,6] The statistical fluctuations are very large but these curves representatively depict the usual trend. The solid curves up to the circles represent typical improvements made during RF processing. The dotted lines indicate the improvements that might be hoped for if the peak power capability were increased to 200 Kwatts.

HIGH POWER RF PROCESSING

As has been mentioned, if RF superconductivity were applied to a TEV linear collider, the peak surface fields required would be = 60 MV/meter. Present concepts of such a linear collider also require the RF to be modulated because Q limitations in presently available materials. [8]

In the past some work has been done with very high power, very short (microsecond), S-Band, RF pulses.[7] The results were promising in terms of the electric field gradients achieved during this short interval. We feel, however, that the pulse durations were too short to apply the information directly to superconducting linear collider requirements which require millisecond or larger pulse widths.

The details of the pulse width, duty factor, and repetition rate are determined by a complex function of the beam current, frequency, bunch spacing, stored energy, filling time, cavity Q, RF power costs, and cryogenic costs. [8]

In view of these requirements, which will not be covered in detail at this time, as well as the capabilities we presently have in our laboratory, the following parameters have been chosen:

Frequency --- 3 Ghz
Peak Power --- 200 Kwatt
Maximum Pulse Width --- 2.5 msec
Average Power --- 1 Kwatt

Consequences of these parameters are as follows:

Minimum $Q_{ext} \approx 10^6$,
Cavity filling time $\approx 10^{-4}$ sec.
Peak electric field at this coupling $\approx$ 100 MV/meter.

RF POWER SOURCE

Several years ago we were able to obtain a surplus, used X3033 Klystron amplifier. These amplifiers had the following specifications:

Frequency = 3 Ghz

Peak Power = 200 Kwatts

Average Power = 50 Kwatts

Maximum Pulse Width = 2.5 msec.

Modulating Anode Current control.

Using this Klystron as the major component, an RF amplifier system has been designed and constructed as shown in Figure 2.

The low current, high voltage power supply was also on hand and the 1 Kwatt average RF power available from such a system is certainly more than enough to couple into average field emission losses.

HIGH POWR TEST STAND

A special cavity has been designed and fabricated at 3 Ghz to match the Klystron frequency. This structure has been so designed as to have a ratio of $E_{peak}/E_{accelerating} = 2$. The resultant structure has a cell to cell coupling of = 2 %. These values were achieved by increasing the cavity nose radius without decreasing the beam hole diameter. Ultimately this will be a more favorable choice in wakefield considerations. We will manufacture these structures in both “one cell” and “three cell” configurations, both of which will be tested.

A sketch of the design of the high power test stand is shown in Figure 3.

The RF power will come through WR284 waveguide from the transmitter and then through a thin teflon window at room temperature outside the cryostat. This window separates the atmosphere from the vacuum required at the cryogenic temperatures.

Inside the cryostat, with cold copper components, there is a “doorknob” transition to 1 5/8” rigid copper coaxial line. In this coax there is a high vacuum coaxial ceramic window into the very clean cavity vacuum.

Above this, the outer coax is a copper plated bellows which will allow the adjustment of the coupling from $Q_{ext}=10^5$ to $Q_{ext}=10^{10}$, This very large ratio in the adjustment range of the coupling is necessary in order to be able to process at very high power ($Q_{ext}=10^5$) and then measure the Q_0 of the structure ($Q_{ext}=10^{10}$) without breaking the cavity vacuum.

About 2 inches of relative motion between the axial RF electric probe and the cavity is required for this coupling range. This coupling will be adjusted by raising and lowering, mechanically, the cavity relative to the RF feed.

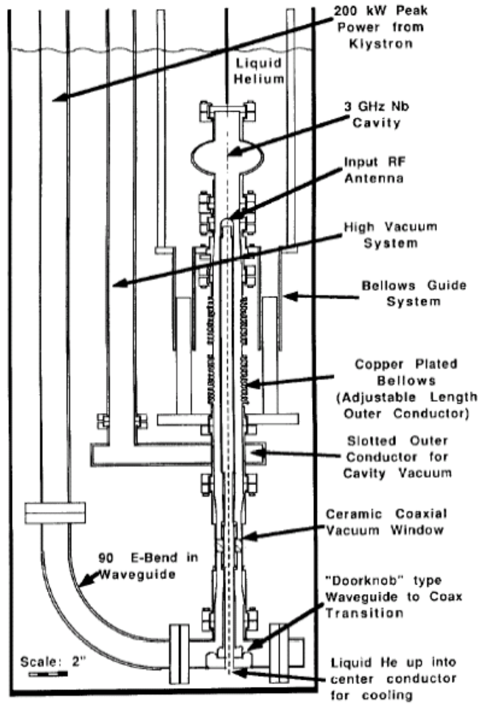

Figure 3.

STATUS

The design for the system is complete. The Klystron transmitter system is finished and has been operated with pulsed DC current to a peak power level of 400 Kwatts, average power level 2 Kwatts, and a pulse width of 2 msec.

RF tests are in progress at this time and the peak RF power has been raised to 50 Kwatts with the same duty factor as the pulsed DC current. This power level should be adequate to test the validity of the concept.

The design and manufacture of the niobium RF cavities is complete except for the final welding.

The design of the test stand is almost complete and manufacture, assembly and test of the various components are now in progress. High power tests of this system will then be made, first at room temperature and then at cryogenic temperatures. Finally, single cell and then three cell structures will be processed and tested.

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