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OPENING REMARKS FOR THE PANEL DISCUSSION ON SUPERCONDUCTING LINAC DEVELOPMENT*

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We have been asked, in making these opening remarks, to be somewhat provocative, at least to the point of stimulating a lively discussion. In this spirit I would like to comment on two problems. The first has to do with the reproducibility and stability of the superconducting properties of practical accelerating structures.

During the past two years high rf fields (≈ 1000 gauss) and high Q's (≈ 10^{11}) have been achieved, first at HEPL[1] and more recently at SLAC,[2] in X-band niobium cavities. Our experience at SLAC has been that obtaining these high Q's and fields is a delicate matter. The slightest misstep in the processing or subsequent handling of the cavities can lead to a serious degradation in the cavity properties. A niobium surface, as it comes from the high temperature furnace in which it is processed, is highly reactive. Can these good results for small X-band cavities, obtained under near ideal conditions, be translated into success in fabricating and processing large-scale superconducting structures? Furthermore, once the structures are installed, can the surface properties be maintained in the environment of an operating accelerator? It seems to me that we have three alternatives: 1) Learn how to carry out the fabrication, processing, installation and subsequent maintenance of the structures to the same exacting standards that seem to be need for success with X-band cavities. 2) Accept the more modest Q's and fields that can be achieved and maintained under less stringent conditions. 3) Find a method to stabilize (by nitridation, anodizing, etc.) the niobium surface so that it will not be so sensitive to its environment. I am not sure the first alternative is really practical, and we should accept the second alternative only if we must. The third alternative will hopefully provide a feasible solution to the surface stability problem. An effort is now being made at several laboratories, including SLAC, to find an appropriate method of surface treatment.

As a second issue that may provoke a considerable difference in opinion, I would like to raise the question of the frequency dependence of the RF magnetic breakdown field. There are very likely a number of causes, perhaps varying considerably in detail, which can lead to magnetic field breakdown. The general effect is probably due to a highly localized power dissipation and consequent heating at imperfections on or in the superconducting surface. There are several potential sources of localized power dissipation which can lead to a frequency dependence for the breakdown field. On a superconducting cavity surface we expect, and usually find upon close examination, topological features of various sorts — cracks and fissures, pits, bumps, ridges, steps, whiskers, etc. There is an enhancement factor for the RF magnetic field at the tips of those features, such as spikes and ridges, which protrude from the surface. As an example, the enhancement factor for a ridge is on the order (1+h/w), where h is the height and w is the width of the ridge.[3] The enhancement factor for a sharp ridge or step could in principle account for the observed reduction in breakdown field below the thermodynamic critical field. A complete discussion of the effect of the enhancement factor on the breakdown field would have to take into account such effects as superheating and the nucleation time for the superconducting to normal state transition. Bypassing these questions, which might be relevant to the problem of a frequency dependence for the breakdown field, we would still expect a contribution to the frequency dependence due to the fact that the probability of finding a perturbation with a given enhancement factor increases as frequency decreases because of the larger cavity surface area.

Cracks and fissures in the surface can also lead to a frequency dependent breakdown field. In such fissures it is possible to have a strong induced electric field.[4] Further, if there is a lossy dielectric in the fissure, the electric field can result in localized heating leading to residual loss and possibly to breakdown. The power dissipation per unit area is given by

$$P_A = \frac{1}{2}\sigma E^2 = \frac{1}{2}(\omega\kappa\epsilon_0 \tan\delta)\, tE^2 \qquad (1)$$

where t is the thickness of the dielectric material, κ is the dielectric constant and tan δ is the loss tangent. Depending on the geometry of the fissure, the induced electric field is related[5] to the magnetic field with a frequency dependence falling in the range $E \sim \omega H$ to $E \sim \omega^{-1}H$. Assuming again that breakdown occurs at some critical value for the power dissipation, we have from Eq. (1) that the frequency dependence of the breakdown field falls in the range $H_b \sim \omega^{-3/2}$ to $H_b \sim \omega^{1/2}$. This latter dependence would be valid at sufficiently high frequencies for the case of a rather pathological fissure which is very narrow compared to its depth, or which is perhaps even re-entrant below the surface. In Ref. 2 some micrographs are shown for a fissure which might fit this description.

There may also be trapped flux quanta and lossy imperfections lying within the superconducting penetration depth. Rabinowitz[6] has given an analysis which attributes magnetic field breakdown to localized heating at such sites. For a small normal region which is comparable in dimension to the penetration depth, the power dissipation per unit area is proportional[7] to ω^2 and the breakdown field scales is ω^{-1}. This dependence again should be modified to take into account the increased probability at lower frequencies for the presence of defects. A frequency dependence for the loss tangent must also be considered.

Finally, it is possible to have a deposit of lossy dielectric near the tips of sharp projections in a region of strong electric field. From Eq. (1) we expect the power dissipation per unit area to be proportional to $\omega\beta^2 E^2$, and the breakdown field to vary as $\omega^{-1/2}$, where β is the field enhancement factor. Again, the dependence of cavity area on frequency might modify or even reverse the sign of the exponent.

References

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