A HAPPY ENDING FOR THE 5TH RF SUPERCONDUCTIVITY WORKSHOP

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1. Introduction

With an expanding field of applications the activity level in rf superconductivity has grown rapidly in recent years. Today there are more than 35 institutions, commercial, government laboratory and academic which are engaged in developing and using this technology for scientific purposes. This community has been remarkably collegial throughout the now almost 30 years of its development. As evidence we can cite the worldwide effort, recorded in these proceedings, which focussed on the "Q disease" being suffered by our host among others as well as the breadth of effort on the TESLA (*T*e*V* *S*uperconducting *L*inear *A*ccelerator) concept as shown in the 2nd TESLA workshop held coterminously this year.

The practical achievements of SRFT (Superconducting radio frequency technology) still fall short of the goals envisioned by its founders, that is rf surface fields in excess of 1000 Gauss and surface resistivities in the nanoohm range. Nevertheless the technology has found many practical uses and there are several new, relatively large applications now under construction which exploit current capabilities. Other near term applications are envisioned. Even bigger potential applications will open up if we can get closer to realizing the demonstrated potential of SRFT.

2. Accomplishments to Date

That SRFT is now robust enough for extensive use can be seen by noting current applications. In the arena of $\beta < 1$ accelerating structures we have the heavy ion linacs at ANL and SUNY, Stonybrook which between them have more than 10^5 operating hours. More of them are under construction as is a cyclotron utilizing SRF Dee's as presented in these proceedings. In the arena of $\beta = 1$ structures wide experience has also been recorded. Together the CERN-Karlsruhe H.E. separators, the recycling linacs at HEPL and Univ. of Darmstadt, and MACSE at Saclay, the synchrotron cavities at CERN and Cornell, DESY and KEK have accumulated well over 10^4 operating hours on line in accelerators. Abuilding are the most extensive uses so far, LEP II and CEBAF and the newest application, the FEL driver, ARES, at INFN, Frascati. All are described in these proceedings.

In addition one may note that commercial production of SRF cavities is now well established, the "Q disease" has been conquered and costs of commercial SRF accelerating sections have been reduced to about 200K$ per meter.

Another measure of accomplishment can be seen in Figure 1 taken from Padamsee's talk in these proceedings. It is a histogram showing the achieved accelerating field in 100 recently constructed structures as of May 1991. To be noted is the mean value of the achieved fields, considerably above the current design value of 5MV/m accelerating.

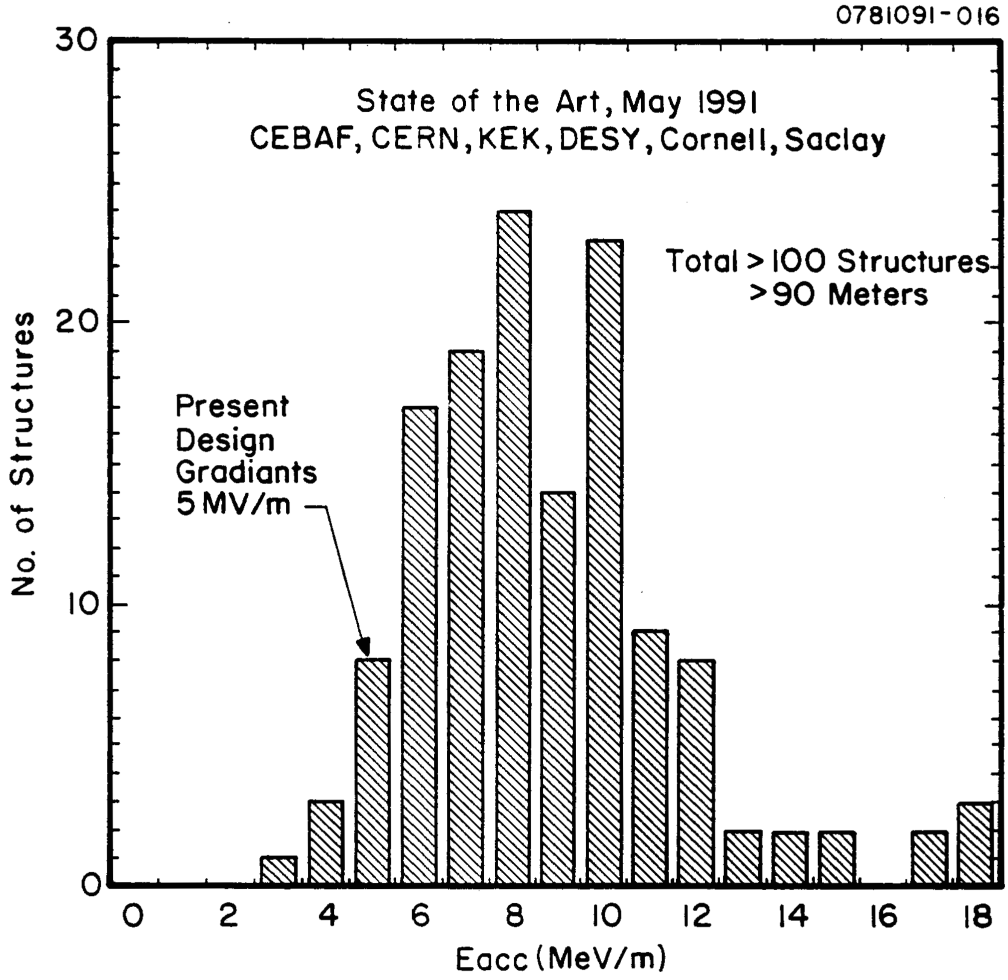

Figure 1.

3. Other Current Opportunities

At this level of achievement, other applications can also be forseen. For example, in the $\beta < 1$ arena, compact RFQ's now seem possible. For $\beta = 1$ structures, serious consideration of use for luminosity frontier storage rings such as CESR B and LHC as well as pulsed electron linacs for compact synchrotron radiation sources

(Novosibirsk) are being given. Some are described in these proceedings.

4. Demonstrated Capabilities

As well as the operational achievements discussed above, progress in demonstration of improvements in fields and Q values continue to be registered.

At low frequencies (100 MHz range) surface fields of 210MV/m and > 1500 Gauss have been demonstrated in millisecond pulsed operation of single elements. At microwave frequencies, surface fields of 150 MV/m (6GHz, cw) and 1500 Gauss (1.5 GHz, cw) have been demonstrated, in single elements, the latter being equivalent to 45 MV/m (accelerating).

In single cell accelerating cavities, surface electric fields equivalent to 30 MV/m (accelerating) have been recorded many times with Q at the operating field of 2×10^9 or more. The low field Q values for these cells is about 10^{10} in each instance.

In multicell, $\beta = 1$, accelerating structures, several instances of 20 MV/m (accelerating) at 1.5 and 3 GHz are reported in these proceedings. The "at field" Q's are 3×10^9 with low field values in excess of 10^{10}.

Other demonstrations of note are the construction of accelerating structures at $<$ 10K\$/m (excluding couplers) and the large scale production of cavities by sputtering onto a copper substrate. These also are detailed in this proceeding.

5. Opportunities for New Applications

These solid operational achievements and recent demonstrations give credence to the hope that significantly improved cost effectiveness can be made available in the forseeable future. It is widely agreed that repeatable achievement of 25 MV/m (accelerating) at $Q \geq 5 \times 10^9$ and structure cost of $\leq$ 50K\$/m would open entirely new horizons for SRFT.

Examples are the TESLA 500 concept, an energy frontier, electron-positron linear collider producing 500 GeV in the CM system, and compact sources for production of both particles and electro-magnetic radiation from infrared to the x-ray region. These sources would have both research and commercial application and as such provide a very strong motivation for further development.

6. Challenges for the Future

To grasp these opportunities and more, we must surmount a number of technical challenges. Methods of control for field emission must be developed further, the ubiquitous residual surface resistance must be understood and reduced and the production cost of structures and cryostats sharply reduced. In addition, for the further future, the potential of new superconducting materials must be explored and developed.

6.1. Field Emission

Today, it appears that the practical limit to achievable accelerating fields and structure Q's is presented by field emission (FE) from high electric field zones in the cavities. This is manifest in the results reported in these proceedings. As far as is known, the bulk of FE is caused by extrinsic sources, that is, foreign particles clinging to the niobium surfaces. Whether there are intrinsic sources is unknown at this time but the possibility cannot be ignored. Evidence to date strongly indicates that every improvement in cleanliness of processing and assembly results in reduced field emission giving strong motive for further improvements in cleanliness of these procedures. New developments in this regard are underway at several laboratories. Some are described in these proceedings. New techniques for processing away existing FE sources have been reported recently. In addition to further work on the "classic" helium processing, the use of UHV baking up to 1500°C with simultaneous oxygen gettering and of high rf power processing (HPP) with millisecond pulses at hundreds of kW have shown dramatic improvements as discussed above under the rubric of "Demonstrated Capabilities". To be shown is that the HPP method is effective at the frequencies (L-band and lower) now favored for future applications. Progress is being made but much remains to be done.

6.2. Linear Costs

There are four target areas for cost reductions, structure design, structure processing, cryostat design and rf systems. Simplification of structure designs is needed to reduce manufacturing cost. As noted above, considerable progress in this direction has already been made. For good yield of intrinsically high field structures low cost methods of ultra clean processing and assembly of the structures need developing. Several laboratories are at work in this area but much remains to be accomplished. One of the most expensive components at present is the cryostat. Design and manufacture simplifications such as have recently been applied to magnet cryostats are needed. Some of these new design ideas have been shown at this 2nd TESLA Workshop. Much work in reducing them to practice remains. In the area of rf power sources, tubes for most applications already exist. However, engineering of their dc power supplies is needed for cost reduction. Perhaps the most significant challenge is in the area of rf power distribution that can permit utilization of the maximum capability of each structure, allow for the possibility of HPP of the structures and at the same time can be economical. Here the surface has only been scratched.

6.3 TESLA Test Bed

In order to focus on these issues in a practical way and to demonstrate that the improvements now envisioned can work together as a whole, some integrated system test is needed. To this end, a number of collaborating institutions will submit a proposal to their respective managements this year for a TESLA Test Bed to be located at DESY. This Test Bed will consist of an electron source, diagnostic instrumentation and up to four 10 meter cryomodules of 1300 MHz superconducting acceleration sections of a design suitable for linear collider service together with the necessary refrigeration and rf sources.

7. Achieving Ultimate Capabilities of SCRFT

Even if reduction measures for FE are highly successful we will still have need of reduced surface resistivities for economical operation at the maximum expected surface fields for niobium, 40-50 MV/m. This will necessitate a new understanding of the mechanism(s) of residual surface resistance. It is possible that there is an intrinsic limit which cannot be circumvented. Today, the limits are simply not known although values as low as $1.5 n\Omega$ have been achieved under special circumstances. Perhaps the observations of "Q disease" in recent years will provide an inspiration allowing a fresh attack on this perplexing problem.

To date, pure niobium cavities have shown by far the highest accelerating fields. The intrinsic critical field for niobium sets a maximum possible accelerating field for cavities of that material. As reported in these proceedings and elsewhere, however, a significant new development has occured. Workers at CERN have developed a method for sputter depositing high quality niobium films onto a copper substrate cavity. Not only is this development important in its own right but it opens up the possibility for application of new, complex materials. One can now envision the use of binary or ternary materials such as Nb_3Sn or NbTiN which have T_c and H_{c_2} substantially higher than niobium itself. If residual resistance can at the same time be controlled, then the 40-50 MV/m barrier would be broken. This is an exciting prospect indeed.

8. Conclusion

Much has indeed been accomplished since the last RF Superconductivity Workshop. This success has opened up many new applications which are now being exploited. The rate of progress has been such that it is reasonable to hope that many new applications will soon be in the offing.