PROCEEDINGS OF SCIENCE

Cold RF R&D

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The perspective to build large accelerators based on high gradient superconducting cavities posed a number of new problems that have been mainly addressed in the preparation of the TESLA project. In this paper I briefly discuss the TESLA Collaboration contributions to the state of the art of the SRF technology and how they have been at the basis of the cold choice for the International Linear Collider. The main ongoing R&D activities in the field are sketched and the perspectives outlined.

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1. INTRODUCTION

Superconducting RF (SRF) has been introduced in the particle accelerator design in the early ’70s, as a valid technology to efficiently transmit energy to a variety of particle beams [1]. For the first few decades the maximum accelerating field reached experimentally was limited by the technologies used for the superconductor and the cavity treatments and handling procedures. In spite of these limitations, the construction and operation of hundreds of moderate gradient (5-8 MV/m) cavities at TJNAF for CEBAF and at CERN for LEP II has been the basis for setting a new level of quality control and industrialization. A deeper understanding of the limiting factors contributed then to revise the SRF technology further, in order to be compatible with the new challenging demands emerging from the High Energy Physics community.

In this context the TESLA challenge to employ SRF as the baseline technology for the future TeV e^+e^- Linear Collider impressed the required momentum to bring forward the SRF technology to a new era, reaching accelerating fields in excess of 35 MV/m with a quality factor (Q) higher then 10^{10}.

A number of new project based on SRF technology have been recently proposed or are in the construction stage. The experience on large existing cryogenic infrastructures and the ongoing work for the LHC allowed to most of the HEP community to be confident that a SRF TeV collider could be built at a cost and with a foreseen reliability that are equivalent to the high frequency normal conducting competitors, while showing a better conversion efficiency and lower operating costs.

The recommendation of the ‘International Technology Recommendation Panel’ to choose the Superconducting RF Technology for the International Linear Collider gave a further push to the already very active SRF community.

2. STATUS OF THE COLD RF TECHNOLOGY AND R& D HIGHLIGHTS

More than a decade of operation of large SRF accelerators showed that bulk niobium structures are preferred to push cavity gradients and quality factors, while magnetron sputtering looks better in some cases (LHC) when beam current is more important than accelerating field. Furthermore, cryogenics systems are highly reliable and are routinely produced by industry. All the ancillaries required to operate the SRF cavities can be properly designed and they proved to be as reliable the one used in conventional RF systems.

In order to obtain high gradients and quality factors the niobium quality needs to be pushed to the possible limit. Thus, quality control during cavity production and surface processing needs to be further improved. Experience has shown that High Pressure Rinsing (HPR) can make the difference concerning field emission aspects.

In order to move to higher gradients, the basic R&D and the technological solutions must move together and, as soon the fabrication procedures are fully understood and documented, the industry can produce good cavities (and even better than R&D laboratories).

In July 1990 the first TESLA Workshop was organized at Cornell by H. Padamsee and U. Amaldi. Two years later the TESLA Collaboration was set up at DESY for the development of a SRF-based TeV e^+e^- Linear Collider. Taking advantage of the experience of all the major laboratories investing in this technology, an optimum cavity design was developed and a large infrastructure was set up at DESY for the cavity processing and test. Stiffening rings were included in the cavity design to minimize the effect of Lorentz-force detuning in the high power pulsed regime. The major contributions came from CERN, Cornell, DESY and CEA-Saclay, but important inputs from TJNAF and KEK were essential. In parallel, from the experience of designing and construction of long SC magnets for hadron colliders, INFN, DESY and FNAL jointly developed, together with the Italian industry, a new concept of an eight-cavity cryomodule with unprecedented cryogenic efficiency.

More than 100 cavities have been industrially produced, all processed and tested at DESY [2]. Details on the fabrication and processing can be found in Ref. [3]. A few key steps determined the success of the high gradient mission: 1) detection of niobium sheet defects and inclusions that pushed industry to invest in the production of a much better material for SRF application; 2) more stringent requirement in term of cleanness and quality control for the industrial fabrication; 3) more stringent specifications and controls for ultra high pure water, chemical compounds and close loop processing plant. Standard Buffered Chemical Polishing (BCP) was applied; 4) wide use of high pressure pure water rinsing (HPR), in clean room environment and with subsequent clean drying, to avoid particles residuals from chemistry; 5) 800 $^\circ$C annealing for hydrogen desorption and 1400 $^\circ$C treatment with Ti getters to improve thermal conductivity.

Using these procedures very low values of the residual resistance (few nΩ) were obtained during tests and the field emission onset was pushed up to around 20 MV/m. The Q drop at high fields was still not curable.

The following steps to approach the physical limits for niobium were mainly determined by the combined introduction of two new ideas originated by the ongoing R&D, mainly at KEK, TJNAF and CEA-Saclay: 1) electro-polishing (EP) instead of BPC to process the cavity active surface in order to smooth out asperities and improve the effect of HPR [4]; 2) moderate temperature baking (100-140°C) in ultra-high vacuum to re-distribute oxygen in the surface, to mitigate resistive effects [5, 6]. The first step raised the onset of field emission, while the second cured the Q drop. The two very important results from the R&D activity for high gradient were independent but, because of the better quality of the electro-polished surface, baking is simpler and more reproducible for the EP cavities.

A few recent TESLA EP cavities demonstrated the cure of the Q drop at high field by 120 $^\circ$C baking [7], according to the EP experience and parameters developed at KEK. The technology transfer was successful, demonstrating that the EP process is a promising technology for reaching the ILC specifications. The outstanding results of these cavities were obtained avoiding the 1400°C heat treatment, thus giving a proof that the niobium quality has been substantially improved by industry. The tests show that the residual resistance has been reduced to a few nΩ. More experimental results, including the long term tests in the horizontal cryomodule of fully equipped cavities are extensively reported elsewhere [8].

EP has also a beneficial effect on field emission [9], even if reproducibility is still a concern. However, the scattering of the field emission onset data demonstrates that further improvements can be expected both on niobium quality, mainly in terms of contamination by small particles, and on the quality control of the processing plant and fluids. Niobium quality remains the major issue in order to fully understand and define Quality Control and Quality Assurance parameters.

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Most of the niobium cost is determined by the effort of preserving quality through casting, rolling and heat treatments required for homogeneous grain, with a reasonable isotropy. Chemistry, and noticeably EP, seems very sensible to the status of the material grains. The amount of niobium required by the cavity R& D has been insufficient up to now to allow special machineries for the sheet manufacturing, without incurring in unbearable costs. R&D work is being pursued at Jlab [10] to obtain large, or even single grain, ingots of pure niobium, to be cut by Electron Discharge Machining (EDM), in order to overcome the small grain material limitations. Preliminary results are very promising and, due to the smoothness of the resulting sheet surfaces, the standard BCP could be reconsidered as the standard process. Clean room assembly procedure could also be improved further for a large SRF based project, and qualified industries would be involved in the process of setting the procedure parameters for a reliable mass scale production.

3. CONCLUSIONS

The worldwide coordinated effort behind the TESLA project has been driving a new level of understanding of the SRF technology limiting factors. High accelerating gradients, close to the physical limits, have been achieved and tested with beam in niobium prototypes.

Most of the recent accelerator projects, under construction or being proposed, are extensively using SRF technology. Industry is producing turn-key reliable systems, including SRF cavities and cryogenic ancillaries. The future European X-FEL project will represent the first large scale application based on the high gradient technology developed by the TESLA Collaboration, possibly followed by other large programs as the FNAL Proton Driver, the CERN SPL, ADS systems for nuclear waste transmutation, as well the many 4^{th} generation light sources based on superconducting RF, which I did not have the possibility to cover in this paper. Their realization would be naturally synergic with the superconducting International Linear Collider.

References

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