Project name

Nonlinear electrodynamic response and nanostructural chemical analysis of RF superconducting cavities

Classification (accelerator/detector:subsystem)

Accelerator

Institution(s) and personnel

University of Wisconsin-Madison, Applied Superconductivity Center:
Alexander V. Gurevich (senior scientist), Peter J. Lee (senior scientist), and David C. Larbalestier (professor)

Contact person

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Project overview

A recent workshop on Niobium for RF Cavities at FNAL reviewed the ongoing work on increasing the operating RF field gradient of superconducting Nb cavities and identified 4 key areas crucial for further progress: 1.Theory of RF superconductivity and nonlinear electromagnetic response, 2. Surface physics, metallurgical problems and materials science, 3. Film technology, 4. Other superconductors. The Applied Superconductivity Center (ASC) of the University of Wisconsin-Madison (UW) has been requested to use its leading expertise in physics and materials science of practical superconductors to help the RF cavity community in these areas.

We propose to address fundamental physics and materials science issues, which determine the performance of Nb cavities under intense RF fields. The goal of this interdisciplinary work is to provide the basic understanding of the nonlinear electromagnetic response of superconductors and identify the key parameters of Nb cavities to be optimized. Specific collaborations with Pierre Bauer (FNAL) on surface impedance measurements and with Hasan Padamsee (Cornell) have been favorably discussed. We have access to state-of-the-art electromagnetic, electron microscopy and surface science equipment and skilled personnel needed to fully characterize superconducting materials. Over many years we have collaborated effectively with the accelerator magnet community.

Description of the first year project activities

Theory. The physics of nonlinear RF response of superconductors in strong RF fields is still not well understood, including such fundamental theoretical issues as the nonlinear RF impedance, the onset of vortex penetration, the subsequent dissipation due to percolative vortex motion along grain boundaries in polycrystals, and the eventual RF superconductivity breakdown. For the characteristic GHz frequency range of Nb cavities, the threshold RF field amplitude $H_a > H_{SH}(T,\omega)$ above which vortex penetration occurs, can be very different from the thermodynamic critical fields H_{c1} and H_c. Gurevich will address these issues, using his expertise in the theory of vortex dynamics in AC fields and current transport through grain boundaries. Using the time-dependent Ginzburg-Landau theory, and the kinetic equations, he will specifically address:

- nonlinear RF impedance $Z(T,H_a,\omega)$ for subcritical AC fields $H_a < H_{SH}$
- critical RF field of vortex penetration $H_{SH}(T,\omega)$ as a function of temperature, and the RF frequency, change of the surface barrier for vortex penetration in RF fields
- influence of grain boundaries on $Z(T,H_a,\omega)$ and $H_{SH}(T,\omega)$
- enhancement of $H_{SH}(T,\omega)$ by surface modification of the superconducting parameters through, for example, local change of the Ginzburg-Landau parameter and resistivity by polishing, vacuum annealing, chemical or electropolishing, or ion implantation.

This theoretical work will be integrated with FNAL, Cornell or other measurements of the nonlinear RF impedance in Nb cavities as a function of temperature, RF amplitude and frequency and the effect of various surface treatments on $Z(T,H_a,\omega)$.

Surface Physics and Chemistry. Electropolishing has been successfully developed and applied to RF cavities by several laboratories, but the reason for the required 120°C bake-out of the RF cavity after electropolishing remains unclear. Lee will microstructurally characterize different electropolished Nb surfaces and examine the issues of the role of O, H or other elements at/near the surface, the importance of sub-oxides and the role of grain boundaries. For instance, the electropolishes and buffered chemical polishes that are currently used are all acid-based and may produce hydrides at the Nb surface; by using a non-acid based electropolish we can indirectly explore the role of hydrogen in cavity performance. We would like to work with FNAL, Cornell or other interested laboratories in developing a test bed for cavity surfaces that uses small sample coupons.

Metallurgical-Mechanical Problems. Traditional methods of yield strength measurement of typical high purity Nb material are made difficult by the large grain sizes in this material. Within the main scope of this proposal we do not plan to address these issues in detail, but we do note that this type of work is well suited to an undergraduate project. We have enjoyed much success with the NSF-REU program and we have several papers published with undergraduate co-authors. In addition to the standard mechanical property measurement equipment available through the UW Materials Science and Engineering program we have a full metallographic laboratory equipped.

Materials science, treatments. Using our Field Emission Scanning Auger microprobe, Lee will characterize the surface chemistry (excluding H) with <100 nm spatial and <1 nm depth resolution. This resolution allows us to characterize potential FE emitters and spark areas. We will make our expertise and facilities available to the RF cavity community so that the surfaces of the existing cavity treatments (BCP, EP, heat treatments) can be compared under identical conditions. We can also use the coupon route to explore processing and heat treatment variations. We also have experience in examining surfaces in cross-section in Transmission Electron Microscopy (both STEM and TEM). As indicated in Section 2 we also propose to examine the influence of H indirectly by changing the electropolishing conditions.

Film technology. We have used dc magnetron sputtering to produce Nb-Ti/Ti and Nb_3Sn multilayers and have used both TEM and FESEM to characterize their microstructures. UW-ASC has leading programs in Nb_3Sn, high-T_c superconductors and MgB_2 including the first epitaxial MgB_2 film. We will use this position to monitor developments in these areas so that in year 2 and beyond we could assess whether other materials than Nb can be exploited for RF cavities. We would like, in collaboration, to address the following issues: 1.Reason for Q degradation at increasing RF field of sputtered films, 2. Intrinsic film problem or due to sputter technique, 3.Role of H in sputtered Nb films, 4. Promise of vacuum arc coating, 5.Whether CVD is a viable method for Nb cavity coating.

Budget

Institution	Item	Cost
UW	3 months salary for A. Gurevich	$21,397
UW	3 months salary for P. Lee	$26,122
UW	Graduate student (1)	$20,000
UW	Administrative	$3,000
UW	Fringe benefits	$19,780
UW	**Total salary & fringe benefits**	$90,299
UW	Travel	$2,500
UW	Materials and supplies	$7,000
UW	Tuition remission 25%	$5,000
UW	Indirect costs (45.5% UW overhead)	$45,409
UW	**Total costs**	**$150,208**