Electropolishing Copper Substrates for Niobium Thin-Film in SRF Technologies

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Electropolishing, the electrochemical removal of surface contaminants and microscopic smoothing of metallic surfaces, has been extensively used as a surface preparation technique for niobium/copper (Nb/Cu) and bulk-Nb superconducting radio frequency (SRF) cavities. Electropolishing of Cu is particularly useful to prepare substrates for Nb thin-film coatings in SRF technology at Jefferson Lab. However, surface roughness and impurities on Cu substrates can negatively influence the efficiency of Nb-Coated superconductors. During the electropolishing process, a current is applied ot the Cu substrate which is submerged in an electrolyte bath; Cu atoms on the highest peaks of the surface oxidize to form ions that travel away from the substrate, resulting in a smoothing of the surface. The focus of this project was to improve the electropolishing of Cu by optimization of various parameters. Test samples were polished in a phosphoric acid and n-butanol bath, and later observed with profilometry and scanning electron microscopy (SEM). Here it is shown that a high and low current density (J_8), electric current per unit area, was identified for optimum polishing. Variables such as bath age, previous mechanical polishing (MP), time, electrode distance, and J_8 combinations were tested to analyze the effect on Cu samples. The results indicate that significant leveling of the Cu surface was achievable through optimization of the parameters considered in this paper. Significant improvements in the efficiency and maximum accelerating field of Cu/Nb cavities may be achievable through this improved electropolishing process at Jefferson Lab.

Development of the SRF Cavity Optical Inspection System

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Superconducting radio frequency (SRF) waves are used to accelerate the particles in the accelerator beam through niobium cavities. Thousands of these niobium cavities must be utilized in the construction of the International Linear Collider (ILC) in the near future. However, given the precise nature of SRF technology, even the smallest defects on the inner surface of the niobium cavities can decrease the maximum acceleration gradient well below its theoretical limit. The optical cavity inspection process for locating these defects is a tiring manual process that proves tedious when inspecting multiple cavities. The focus of this project was to increase the efficiency of the scanning of the cavities through the automation of the inspection process. Through the use of basic materials such pulse motors, basic aluminum metal stock and a telescope coupled with a charged couple device (CCD) digital camera for hardware and Visual Basic express 2008 to program the software, the SRF optical cavity inspection system was automated with features including an automated rotational system and a program that automatically scans the cavity for defects. A polar coordinate system was also implemented maping the inner surface of niobium cavity allowing a reference point for locating inner defects that adversely affect the cavity's performance. Upon the project's completion, the cavity inspection process should be far more efficient with automated features and a user-friendly interface that allows more precision in locating the defects. The program will allow each cavity's defects to be repaired through a pinpoint chemical wash technique rather than replacing the entire cell on which the defect is located. The automation of the cavity inspection system will improve the data acquisition efficiently and increase the reliability of the findings as well. The automation of the cavity system will also greatly improve the cost efficiency in which the cavities can be processed and repaired and is a major step in preparing for the construction of the new ILC in the near future.

The Parameterization of SRF Niobium Cavities

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The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory uses elliptically-shaped Superconducting Radio Frequency (SRF) cavities to accelerate electrons to energies approaching 6 GV. These cavities are made from sheets of fine-grain niobium that are forged and rolled from a niobium ingot. CEBAF created the so-called "C-50_ program to refurbish inefficient cavities and increase the accelerator gradient E_{acc}", while reducing Radio Frequency (RF) losses. The C-50 cavities were treated with Buffered Chemical Polishing (BCP) and High Pressure Rinsing (HPR) to remove any impurities found on the cavity surface. Prior to going into the accelerator, the cavities then were tested using high RF power represented graphically as the quality factor Q_0 against the E_{acc} (MV/m). The focus of this research was to emphasize specific changes commonly ignored in C-50 cavities by linearly plotting the Surface Resistance (nΩ) against the Eacc and by analyzing and parameterizing the middle field of C-50 as well as ILC and DESY cavity plots. The primary step in analyzing the middle field was to convert the Q_0 value into the surface resistance. Data was taken for many C-50, ILC and DESY cavities plotted linearly and fitted with various difference parameterization techniques in order to extract a common fit for all cavities. The 4th order polynomial fit equation was the best fit for all cavities, yielding five constants. After numerous manipulations, difference programming and graphing techniques, the results indicate that the following parameterization equation:

$$R = T + S \times E + (R_0 - T) \times [1-(E/U)^2 \times [1 - (E/V)]^2 \qquad (1)$$

fits the data, not only for all of the C-50 cavities, but also for the ILC cavities from JLab and DESY. Furthermore, the middle field "bump" is always present regardless of the difference cleaning methods performed on the cavities. This study makes no attempt to explain the significance of this parameterization, but it does provide an indication of the underlying physics which will be followed in future studies.

Controlling Electron Bunch Spacing with a New Beat Frequency Modulator

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The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory uses a DC high-voltage GaAs photogun to supply a continuous train of electron bunches known as the electron “beam”. The electron bunches are generated by drive lasers pulsing at 499 MHz synchronous with the radio-frequency cavities of the accelerator, consequently the bunch spacing for typical experiments is 2 ns. Experiments at CEBAF can sometimes benefit from the bunch spacing being longer (>10 ns) to allow the detectors to better distinguish time-dependent signal from background, however, the drive laser does nto have sufficient band-width for such low repetition rates (<100 MHz). The focus of this experiment is to implement a device that will use the existing drive lasers, yet allow the electron bunch spacing at the experiment to increase. To achieve this, a new radio-frequency electronic device called the Beat Frequency Modulator (BFM) was constructed. The BFM lowers the repetition rate of the drive laser to a sub-harmonic frequency within an acceptable range (400-500 MHz) so that this new train of electron bunches “beat” against a fixed 499 MHz radio-frequency chopping cavity, allowing only bunches at the difference in frequencies to pass. The BFM was fabricated and bench tested with a spectrum analyzer. The BFM will be tested with the electron gun and used in an experiment to limit background at the injector Mott polarimeter detectors, by operating with bunch spacing greater than 10 ns. The successful design construction and installation of the BFM will allow physicists at Jefferson Lab to obtain more precise data by going them a range of electron bunch spacing than can dependent on their experiment.

New Wien Filter at the Continuous Electron Beam Accelerator Facility (CEBAF)

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A new beam line containing a Wien filter will be installed at the Continuous Electron Beam Accelerator Facility (CEBAF) injector as part of an upgraded 4π spin manipulation system for the PREX experiment. The spin of each of the beam electrons process along the journey from the polarized electron source to the end-station experiment. A Wien filter, a device possessing both an electric and magnetic field, rotates the spin direction to precisely compensate the accelerator journey and control the ultimate orientation at the target. The optically asymmetric nature of the Wien filter, however, must be accounted for and is done so with quadrupole magnets. The focus of this project is to characterize the new Wien filter and beam line. The required magnetic was determined by calculation and compared with measurement. Optimization of the quadrupole magnets is done by defining the beam size and divergence using the code Elegant. It is shown that the analysis and modeling support the beam line design with the intended goal of injecting into the accelerator an electron beam with control over the final spin orientation at the experimental target. This control over the final spin orientation allows for more precise and efficient measurements in each of the experimental halls.

Hydrogen Outgassing in Stainless Steel Gun Chambers

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Vacuum quality is an important aspect in electron guns. The hydrogen outgassing rate is a determinant of the vacuum quality in stainless steel gun chambers. A low outgassing rate allows for a better vacuum and therefore a longer photocathode lifetime. Low outgassing rates depend on thermal treatments of the chamber. The purpose of this project is to put together a gun chamber, and assess the hydrogen outgassing rate after an administered thermal treatment. To determine the hydrogen outgassing rate, pressure measurements of the vacuum chamber must be taken. Once these measurements have been obtained, they can be used along with the known volume and surface area of the chamber to calculate the outgassing rate. A thermal treatment of 400^{o} C for nine days achieved an outgassing rate of 1.12×10^{-13} Torr L/s cm^2. The value obtained for the hydrogen outgassing rate is one order of magnitude better than previous outgassing rates. This is because in the past, this specific thermal treatment has never been used. This improvement illustrates the success of the project.

RTPC for Low-Energy α-Particle Detection in the Experimental Search for Hybrid Mesons

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The theory governing the strong interaction between partons (quarks, q and gluons, g) in the standard model of particle physics, quantum chromodynamics (QCD), allows a large variety of bound states, known as hadrons. Any combination of quarks and/or gluons can exist as long as their respective color charges negate to zero. Nearly every hadron observed however is in a qqq (baryonic) or q (mesonic) configuration. These are the particles predicted by the well-known quark model, however so-called exotic states are also allowed by QCD, such as glueballs (gg), pentaquarks (qqqq), hybrid mesons (gq), etc. Some of these short-lived exotic states can be identified by their unique quantum numbers, but others are indistinguishable from ordinary hadrons. The detection of exotic hadrons has so far been shrouded in controversy, and as such we are seeking evidence of the ground state hybrid meson π1 with quantum numbers JPC = 1−+ via photoproduction utilizing the 6-GeV electron beam off of 4He nuclei. A key factor in our experiment is the use of 4He nucleons due to the 4He nuclei being spin- & isospinless, thus greatly simplifying the partial-wave analysis (PWA) thanks to the re- sulting coherent photoproduction process and subsequent elimination of noise from nucleon-resonance production. The foundation of the experiment however is in the use of a radial time-projection chamber (RTPC) to detect the low-energy recoiling 4He nuclei. The RTPC has cylindrical gas electron multipliers (GEMs) with almost 360° cover- age for detection, similar to the successful barely off-shell nucleon structure (BoNuS) experiment. Two mass-energies have tentatively been detected for the ground-state π1, though there can only be one: 1.4 GeV & 1.6 GeV (theory predicts ≈ 2 GeV/c2). De tection of the π1 at Jefferson Laboratory will be a big step towards ending the controversy surrounding exotic hadrons and furthering our knowledge of the still-elusive quark-gluon behavior and the strong force.