Modeling, Fabrication, and Optimization of Niobium Cavities

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Task 2

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BACKGROUND

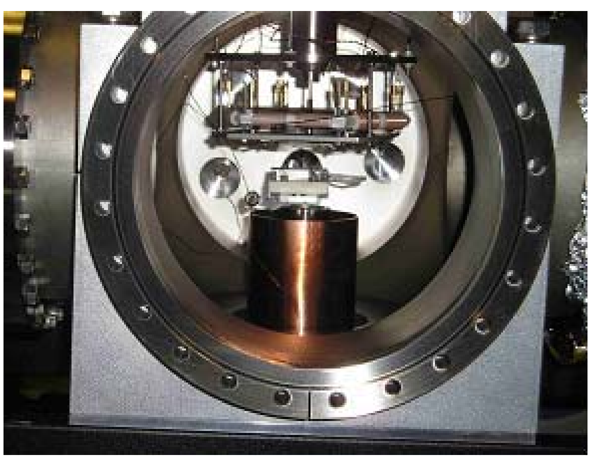
One of the key technologies for the deployment of accelerator-driven transmutation systems is the accelerator itself. Elliptical superconducting niobium cavities are used to increase the efficiency of the high-power accelerators needed to support the transmutation mission.

One of the major sources of energy loss from a superconducting accelerator cavity is a process known as multiple impacting (or "multipacting") of electrons. This phenomenon limits the maximum amount of energy and power that the niobium cavity can store. As a result, the maximum power available for accelerating the desired charge, as well as the overall performance of the accelerator is reduced. Furthermore, the energy absorbed as a result of multipacting eventually turns into heat. This negatively impacts the performance of both the superconducting cavity and the accelerator.

RESEARCH OBJECTIVES AND METHODS

This project is tasked with examining the impacts of the design and fabrication technologies for these elliptical niobium cavities on their performance. Niobium was selected primarily due to its behavior at low temperatures.

One objective of this study is to experimentally model the fluid flow resulting in the chemical etching of a niobium cavities with the aid of a baffle. Numerical analyses tend to show that the current etching process with baffle does not uniformly etch the cavity surface. Multiple cavity cell geometries are to be investigated. Optimization techniques will be applied in search of the chemical etching processes, which will lead to cavity walls with near ideal properties.



Side view of the secondary electron emission system. The components from top to bottom are: electron gun end, electron beam tube, particle position detector, micro-channel plate stack, business end of the manipulator arm, top of cryostat, and cryostat thermal guard.

Codes are to be modified to provide a statistical study of impacting in the multicavity geometry. Optimization techniques to be developed based on the desired resonant frequency of the geometry and/or on the multipacting condition. An existing vacuum system was, in part, modified for multipacting experiments.

Modeling codes, optimization techniques, and experimentation will provide UNLV researchers with a well-rounded study to examine existing and novel niobium cavity designs for the superconducting radio frequency high-current accelerator.

RESEARCH ACCOMPLISHMENTS

Development of Optimization Model: A framework for interacting two dimensional field codes and an optimization program was created. The code has been used to optimize the end cell of a five-cell niobium cavity based on resonant frequency and mode. Multipacting studies are well underway for this new geometry.

SEE (Secondary Electron Emission) Studies: The vacuum chamber with electron gun, particle position detector, pumps, pressure gauges, three-axis manipulator arm, cryostat, and residual gas analyzer (RGA) have been assembled. The vacuum environment has reached its target (less than $1x10^{-8}$ Torr) without the need for baking the chamber.

Niobium samples have been cleaned both at LANL and Cornell University and await experimentation. Computer simulations have been conducted to aid in the study of the secondary electron trajectories based on the original design of the vacuum chamber with gun, detector, cryostat and sample system.

The experimental setup appears to be unique and may offer further insights to the SEE process not attained elsewhere. A Monte Carlo secondary electron emission code based on the "Single Scatter" approach was obtained from Dr. David Joy (of both ORNL and University of Tennessee.). The "Single Scatter" approach follows each individual charged particle through the entire cascade. The code is being modified to allow for surface layer contaminants in the hopes to verify experimental studies. The code may only be able to supply approximate results since some of the inherent mechanisms internal to the code are valid at higher primary beam energies.

Revised Etching Process: The current etching method, which uses a baffle to direct the etching fluid toward the surface of the cavity, partially succeeded in achieving its task. However, flow was restricted to the right half of the cavity with very limited circulation in the left half. An alternative design was proposed and modeled. The exit flow is now parallel to flow inlet. Results show that flow circulation was eliminated. The flow is now closer to the surface of the cavity. Optimization techniques were used to improve this design.

Developed Flow Visualization System: To confirm the predictions from the fluid flow models used to analyze the etching process, the UNLV team developed and deployed a flow visualization system. A complete experimental setup, including a computer-controlled x-y traverse and digital camera, was assembled. Flow visualization experiments using a plastic prototype of the niobium cavity used dye injection. Dye injection provided quantitative verification that laminar flow exists within the niobium cavities during etching. Additionally, it verified the absence of re-circulation pockets within the cavities.

FUTURE WORK

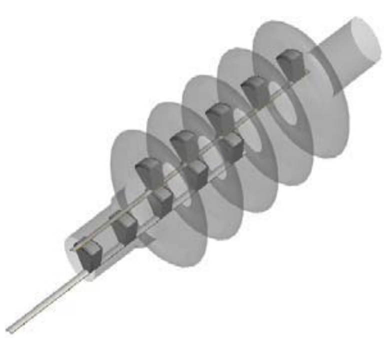
Future work will conclude experimental studies of flow characteristics and compare these to simulation. Alternative baffle studies may be improved upon based on fluid flow models. Designing an expanding baffle presents a challenge due to space limitations and the chemically aggressive environment.

HIGHLIGHTS

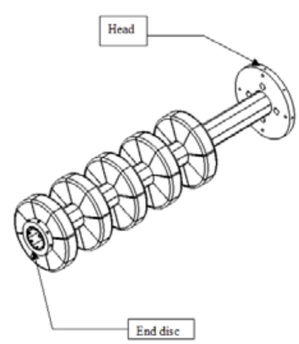
- Sathish Subramanian completed his M.S. in Mechanical Engineering (December 2003), thesis entitled “Modeling, Optimization, and Flow Visualization of Chemical Etching Process in Niobium Cavities.”
- “Optimization of a Five-cell Niobium Cavity” presented at the ANS Annual Meeting, San Diego, CA, June 1-5, 2003.
- “Preparation Studies for Secondary Electron Emission Experiments on Superconducting Niobium,” 2004 ANS Student Conference, at University of Wisconsin, Madison, April 1-4, 2004. Anoop George received an Outstanding Student Paper award.

Optimization techniques have been imbedded in a MATLAB controlling code based on the desired resonant frequency and mode of operation. The optimized geometries are to be examined using multipacting codes and compared to the existing LANL five-cell cavity. The controlling code will also be modified to allow mid-cell parameters to be optimized.

Secondary electron emission experiments are to be conducted on niobium at superconducting temperatures in the last year of this research. The data obtained from this study will be made available for multipacting codes.



Assembling UNLV Baffle inside cavity



Assembled Optimized UNLV Baffle

Optimized UNLV Baffle inside cavity

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