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Modeling, Fabrication, and Optimization of Niobium Cavities

Robert A. Schill Jr.
University of Nevada, Las Vegas, robert.schill@unlv.edu

Mohamed Trabia
University of Nevada, Las Vegas, mbt@me.unlv.edu

Yitung Chen
University of Nevada, Las Vegas, yitung.chen@unlv.edu

Task 2

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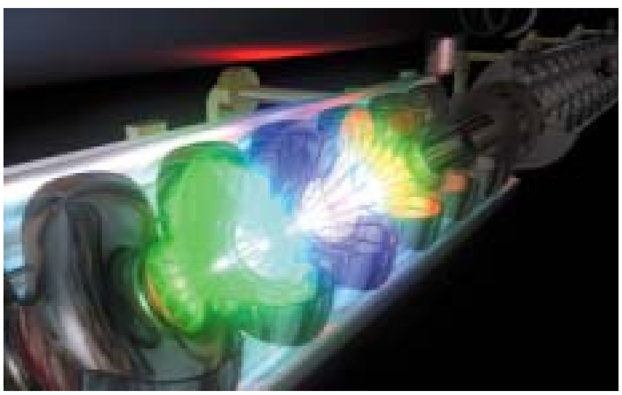
R.A. Schill, Jr., M.B. Trabia, and Y. Chen

GOAL AND BACKGROUND

All technologies for the transmutation of nuclear waste require a large source of neutrons. One of the principal methods of generating these neutrons is by using a particle accelerator to bombard a heavy metal target. One of the more promising designs for particle accelerators for transmutation systems is the Superconducting Radio Frequency (RF) high-current linear accelerator (linac). The power supplies for these systems have three major components: niobium cavities, power couplers, and cryomodules. This research project will develop models to predict the behavior and performance of the niobium cavities, which will then be used to design and optimize the superconducting structures.



Picture of a niobium cavity for superconducting systems

A phenomenon known as "multipacting" limits the maximum amount of energy and power that the niobium cavity can store. This phenomenon occurs when energy needed to accelerate electrons is "stolen" from the cavity. As a result, power available to accelerate the proton or other particles is decreased. Therefore, the overall performance of the accelerator is reduced, or additional energy must be put into the system to accelerate the particle. To make the problem worse, the energy "stolen" by these electrons eventually turns into heat. This also negatively impacts accelerator performance.

One potential cause of multipacting is the presence of chemical products or foreign particles on the surface of a niobium cavity. To address this potential source of multipacting, the cavity walls are polished after manufacturing using chemical etching and high pressure rinsing. These cavities are not easy to manufacture, however, and may have unusual shapes and sizes that complicate this processing step. Researchers at Los Alamos National Laboratory propose using a baffle to improve uniformity in the etching process. The baffle is inserted inside the cavity to help direct the etching fluid toward the walls of the cavity to produce a cavity with maximum surface quality and minimal multipacting losses. While a number of designs for this technique have been identified, the cavities are difficult to manufacture and result in a heterogeneous surface etch which damages grain structure.

The UNLV research group, working with collaborators from Los Alamos National Laboratory, is studying this problem and working toward techniques to optimize the design of these superconducting cavities. This is expected to have a direct impact on the performance of the large superconducting particle accelerators required for Accelerator-Driven Systems to transmute nuclear waste.

OBJECTIVES

The overall goal of this research project is to develop a stronger understanding of the multipacting phenomenon, and to use this understanding to optimize the design of niobium cavities to minimize or eliminate this parasitic phenomenon. To achieve this goal, the research team established the following objectives for the first year of this program:

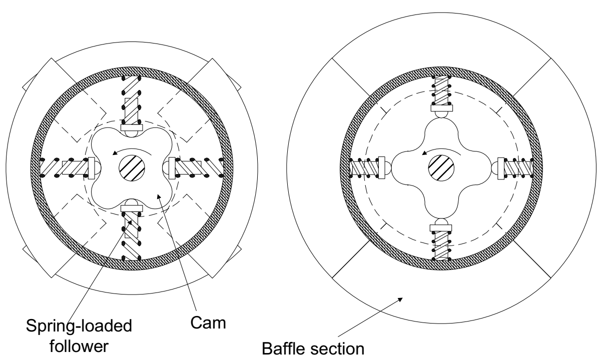
- to study the effect of multipacting on niobium cavities with single and multiple cells;
- to improve the uniformity of surface finish in chemical etching;
- to investigate the relationship between the shape and surface condition of the cell and its performance; and,
- to provide a systematic approach for improving the performance of the niobium cavities.

ACCOMPLISHMENTS

To address this problem, the research group began three simultaneous research tracks: a multipacting study, a computational fluid dynamics study (CFD), and an optimization study. These tracks worked on the problem in parallel, exchanging information and models as they were developed.

The multipacting track utilized commercial codes, a research code, and numerical analysis programs developed at UNLV to investigate particle tracking and multipacting. Ms. Myong Holl, a Mechanical Engineering undergraduate student, learned the suite of commercial codes purchased and assisted in simulating multipacting studies. Limitations in the research code were identified and addressed with the author of the code in person. Modifications made in the research code permitted examination of localized secondary electron emission and impacting over the cavity surface. The commercial and research codes failed to track individual emitted particles. Therefore, a scheme that identifies potential multipacting locations was developed. Additionally, confidence in the validity of the codes was established through examining RF field resonance and particle tracking. A numerical analysis program that was developed permitted investigators to draw a single cell elliptic niobium cavity as well as a five-cell cavity. LANL's five-cell elliptic cavity was then modeled. Multiple codes written by the research team augmented the commercial and research codes and enhanced computer capabilities.

The CFD track provided a means to evaluate the current chemical etching process. During this study, the accuracy of the software used as a modeling tool was verified. Software variables were adjusted as needed. A finite element model for the proposed five-cell niobium cavity with a baffle was developed and a parametric study of the problem was conducted. This involved altering the variables that describe the geometry and location of the baffle subject to the constraint imposed by the cavity. Findings indicated that no scenario improved the performance index of the proposed baffle design. Through the optimization study, a modified design using an expanding baffle was developed. Although the results were deemed satisfactory (flow circulation was eliminated, and flow is closer to the surface of the cavity), mathematical steps were taken to improve the modified baffle design. The algorithm reached a solution after numerous function evaluations. The possible design for an expanding baffle and, thus, the velocity field for the optimized modified baffle design is depicted below.



a. Retracted Baffle

b. Expanded Baffle

HIGHLIGHTS

- S. Subramanian, Q. Xue, M. Trabia, Y. Chen, and R. Schill, "Modeling and Optimization of the Chemical Etching Process in Niobium Cavities" accepted for publication in the International Congress on Advanced Nuclear Power Plants (ICAPP).
- M.S. Thesis, "CFD Simulation of Niobium Cavity Etching Process," Qin Xue, August 2002.
- Dr. Stan Humphries, author of the RF Trak research code, presented a seminar in March 2002.
- Travel to Los Alamos National Laboratory established positive working relations with LANL colleagues and assisted in understanding the concerns and interests of LANL relative to this research.

Professor Trabia, Professor Schill, and graduate student S. Subramanian with a model of a cavity.

CONTINUED PROGRESS AND FUTURE GOALS

Future work involves modifying the models to bin the five-cell geometry and implement statistical analyses into code. In order to determine some of the parameters necessary for the modeling work, it will be necessary to perform some experiments on the nature of multipacting, and the properties of the niobium cavities in regards to this phenomenon. To support these experiments, some refurbishment of an existing vacuum system needs to be performed in the next proposal period. These modifications will allow the study of secondary emission properties of a Los Alamos surface treated niobium target being bombarded by electrons from an electron gun. The results of this work will be incorporated into the system models, which can then be used for another iteration of the cavity design and optimization work.

Research Staff
Robert A. Schill, Jr., Co-Principal Investigator, Associate Professor, Department of Electrical and Computer Engineering
Mohamed B. Trabia, Co-Principal Investigator, Chair, Mechanical Engineering Department
Yitung Chen, Assistant Director, UNLV Nevada Center for Advanced Computational Methods

Students
Qin Xue, Satishkumar Subramanian, and Anoop George, Graduate Students
Myong Holl and Greg Loll, Undergraduate Students

Collaborators
K.C. Dominic Chan, Project Leader, SCRF Engineering Development and Demonstration, Los Alamos National Laboratory
Tsuyoshi Tajima, Team Leader, Accelerator Physics & Engineering, LANSCE-1, Los Alamos National Laboratory