

AN OVERVIEW OF NORMAL CONDUCTING RADIO FREQUENCY PROJECTS AND MANUFACTURING CAPABILITIES AT RADIABEAM TECHNOLOGIES, LLC*

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Abstract

Radiabeam Technologies (RBT) is actively engaged in manufacturing 8 different Normal Conducting Radio Frequency (NCRF) accelerating and diagnostic structures. These NCRF programs include compact X-band industrial systems, laboratory grade NCRF photoinjectors, deflecting cavities and High-Gradient structures. Nearly all aspects of these NCRF structures' lifecycle are performed in house, including design, engineering, fabrication, cleaning and RF cold testing and low power RF hot testing. An overview of these varied projects along with references to more detailed publications presented in this conference is provided. Further details concerning specific processes applicable to all abovementioned RF projects will also be discussed.

INTRODUCTION

While there are several large companies that manufacture accelerator structures for certain commercial applications, RadiaBeam is, to our knowledge the only full-service manufacturer of custom RF structures for a wide range of applications. RadiaBeam is unique in its combination of resources in design, simulations, engineering, machining, and RF-testing. Furthermore, RadiaBeam is actively developing the in-house capability to produce high-gradient (≥ 50 MV/m) S- and X-band structures, for applications where a high energy beam must be obtained in a limited space.

RadiaBeam's developments in this area are currently funded by several SBIR Phase II projects from DOE and DHS. The specifics of the various projects are discussed in the following sections. The structures being developed range from L-band photoinjector guns, to X-band deflecting cavities, to industrial linacs. However, they all have in common a process flow that starts with design, continues to engineering, then proceeds to manufacturing, and validation. We discuss these steps in detail below.

NCRF DESIGN / ENGINEERING

At the cornerstone of our in-house capabilities is the ability to completely design from first concept to final engineering NCRF structures and components. The design process first begins with an examination of the customer's requirements. For commercial applications, this often begins with Monte-Carlo simulations to determine the beam current required to produce the specified dose rate. For research applications, customers provide very detailed usually challenging, specifications for beam output. In

both cases, once the RF structure performance has been fully specified, the next step is electromagnetic design of the structure that can achieve the specifications.

RF Design

The initial phase of work required to realize an actual device is to determine its operating parameters and establish the frequency of operation, desired mode, shunt impedance, quality factor, mode separation, number of cells, power requirement and efficiency. Analytical calculations then inform the baseline input into 2-D electromagnetic codes, such as SUPERFISH[1], for initial estimation of the main RF parameters mentioned above. The electromagnetic fields obtained with SUPERFISH are then used as input for beam dynamics simulations performed with 2D codes like PARMELA. In order to finalize coupler designs and obtain complete results, including the amplitude and phase of the electromagnetic fields, the 3D numerical code HFSS 13.0 is employed. Also, there is the possibility of exporting HFSS fields and utilize them in PARMELA simulations.

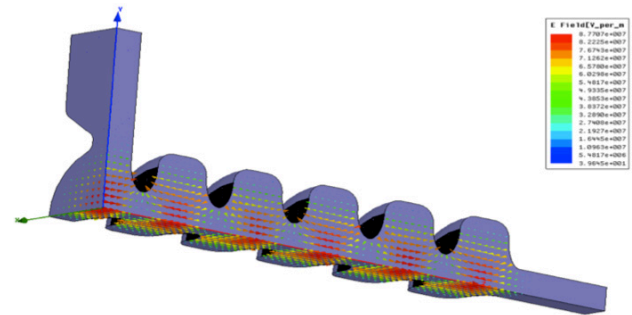


Figure 1: A HFSS13 plot of the accelerating gradient.

Thermo-Mechanical Design

Prior to finalizing RF design, thermo-mechanical modeling with ANSYS 13.0 is performed. The ability to directly import structure power distributions from HFSS into ANSYS permits an accurate and informative parameter space from which structure deformation studies, temperature distribution and calculation of the equivalent (von-Mises) stress can be evaluated. The results of this analysis will inform the ideal locations and geometries of cooling features required for sufficient thermal management. The ability to re-input the thermally distorted model back into HFSS further provides a powerful means to effectively validate the thermal stabilization design to ensure RF heating will not detune the structure and render it inoperable. Following this

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analysis, preliminary mechanical design will be undertaken through direct import of the ANSYS model into the 3-D solid modeling platform, Solidworks.

Mechanical design and engineering will then take into consideration issues including, but not limited to, component manufacturability and precision repeatability, ability to incorporate reliable brazing/bonding features, the ability to incorporate structural support systems, UHV pumping feedthroughs and ease of cleaning and handling. If modifications to cooling geometries are required following this iterative stage of the efforts, additional modifications will be made to the thermal stabilization features and once again undergo engineering review. Finally, FEA work may also be performed in ANSYS to optimize the placement and thermal expansion capabilities of structural supports.

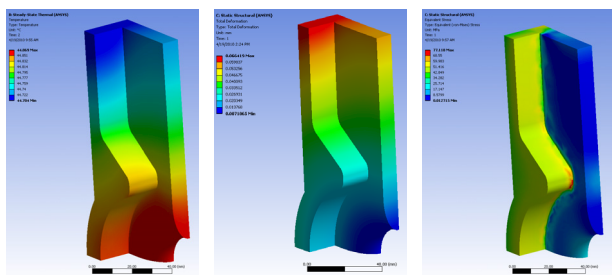


Figure 2: ANSYS analysis of thermal distribution, mechanical distortion and von Mises stress of a high gradient NCRF coupler.

MANUFACTURING

Radiabeam Technologies has recently made significant investments in equipment and infrastructure in order to support our NCRF R&D program.

Equipment

Internal cell feature deviations in the sub-thousands of an inch range from design values will shift the resonant frequency of the cell and can prevent the structure from functioning. Although this precision and accuracy is achievable with conventional CNC lathe machining utilizing carbide or polycrystalline diamond cutting tools, we are closing in on the limits of such machines. To ensure we will achieve this end, we have validated the ability of our new CNC lathe and mills to accomplish this task. Further key investments in our NCRF program include an in-house part cleaning facility, a Class 100 clean room and dedicated part dry storage and transport units.

Tooling

When concerned about RF breakdown, the surface finish of internal cell features is critical. Surface finishes are directly related to CNC machine vibrational stability, tool holder table motion fluidity, cutting feeds and cutting speeds. Most all NCRF copper structures manufactured in-house use polycrystalline diamond cutting tools for

turned geometries due to the superior quality of surface finishes (~6 micro-inch RMS) they generate. We will utilize the tool presetter built into the lathe to accurately fiducialize the cutting tool to the workpiece.



Figure 3: Radiabeam's Haas SL-10 CNC Turning Center and Class 100 cleanroom.

Handling / Controls

Ultimately, the ability to maintain full control and oversight over the manufacturing process is invaluable in NCRF structure manufacturing, particularly in regards to high gradient NCRF structures. As many of the sources of high gradient structure breakdown can be attributed to contamination, a high priority has been placed on controlling these potential sources. This effort is part of ongoing development at Radiabeam Technologies with the current construction of a dedicated clean manufacturing room. Surface contaminants such as oil and dust can interfere with the joining process (whether diffusion bonding or oven brazing), be a source for inadvertent scratching and etching of the surface and most importantly serve as sources for RF breakdown, therefore focused vigilance particularly during final manufacturing stages is employed.

Further process controls are established through formalized Ultra High Vacuum / RF manufacturing guidelines. Such guidelines prohibit the use of sulfur bearing cutting fluids and require that prior to most RF work, as a part of routine, we flush and replace the coolant. Handling specifications regarding the workholding materials, gloved handling of components, overnight storage procedures and part tracking and manufacturing condition recording are also implemented.

VALIDATION

Two test stands are used to evaluate the state of the cells. The single-cell test stand (SCTS) measures the properties of a single resonant cavity, while the bead-pull test stand (BPTS), significantly more complex, measures the properties of this same cell (and all the others) within the context of the entire structure's properties. The SCTS allows us to put an upper bound on acceptance criteria for the BPTS, and is a relatively fast and simple test to monitor for outliers and to allow for prompt feedback to manufacturing. The cells passing examination by the SCTS are stacked into the BPTS. The BPTS has a repeatability of 500 kHz standard deviation. If successive

scans are run without any change in conditions, then we see a standard deviation on the order of 40 kHz. This repeatability is sufficient for x-band structure characterization, where post braze tuning of 15 MHz is reasonable. The same BPTS is utilized for post metallurgical bonding tuning of the structure.

ONGOING PROJECTS

High Gradient Structures

Currently 3 high gradient NCRF structures are in various stages of design, engineering and fabrication. The X-Band Traveling Wave Deflector (XTD)[3] is designed to perform longitudinal characterization of sub-picosecond ultra-relativistic electron beams and operates at 11.424 GHz, and features short filling time, femtosecond resolution, and a small footprint. This structure is currently in manufacture and slated for installation in the Accelerator Test Facility at Brookhaven National Laboratory.

The Dual Energy Compact Accelerator (DECA) S-band structure[4] is a 50 MV/m standing wave linac design for high gradient, but modest power operation. Envisioned as a utilitarian device for widespread adoption in footprint limited facilities or mobile platforms, this structure is currently entering the thermo-mechanical design and prototype manufacturing phase with full manufacturing expected to begin this summer.

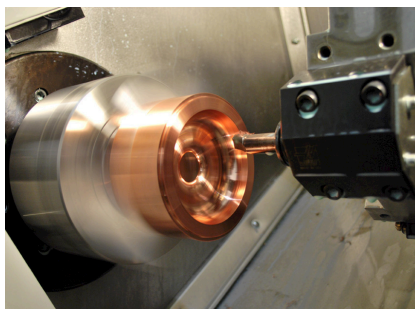


Figure 4: Prototype manufacturing of a DECA cell

As a change from typical R&D activities at RBT, the final high gradient structure were are currently working on is a NCRF Photocathode based gun for Sincrotrone Trieste[5]. This project, lead by Radiabeam Technologies, requires multi-institutional coordination with RF design completed by UCLA and RBT, engineering work performed by MATS, brazing undertaken at INFN and final tuning and characterization by RBT and MATS. The baseline design for the gun utilizes fat lip / racetrack coupler with a single RF feed and is designed for 120 MV/m operation.

Industrial LINACs

RadiaBeam is actively developing the capability to produce complete industrial linac systems for a wide variety of applications, from radiography to sterilization. In general, this consists of standard, low-gradient S-band 5 – 10 MeV linacs, with beam power in the range of 100

W to 100 kW. However, we are also developing a novel type of linac, which we call the MicroLinac.

The MicroLinac is unique in its focus on providing a low-cost, compact solution for the replacement of radioisotopes (e.g. Ir-192 and Cs-137) in industrial applications. The core of the device consists of a short 9.3 GHz standing-wave accelerating structure powered by an inexpensive magnetron.

Prototypes of the MicroLinac for two different applications are currently being produced, funded with two Phase II SBIR contracts (one from DHS, the other from DOE[6]). One version will be a portable replacement for radiography isotope sources such as Ir-192. The other will be a higher energy and higher power version for use in self-contained irradiators for research and blood irradiation (i.e. Cs-137 replacement).

Other NCRF Guns

Driven by the need for higher repetition rates in NCRF photoinjectors, RadiaBeam has been investigating the use of advanced cooling designs using Solid Freeform Fabrication (SFF). SFF utilizes a type of 3D “printing”, based on electron beam melting of copper powder, to construct structures with internal features. RadiaBeam is currently developing two photoinjectors utilizing this technique - a high repetition rate and high gradient, S-Band gun [7], and a CW, very high average power, L-band gun [8].

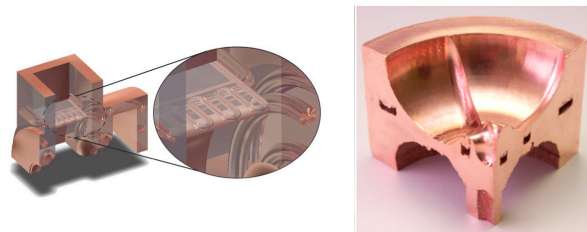


Figure 5: CAD rendering of a NCRF gun with SFF cooling channels (left) and a partial sample cell manufactured with the SFF technique.

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