# FABRICATION OF A MODEL POLYHEDRAL SUPERCONDUCTING CAVITY*

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*Abstract*

The polyhedral cavity is a superconducting cavity structure in which a multi-cell cavity is built from a Roman-arch assembly of arc segments. Each segment has a Tesla-like r-z profile, and is fabricated either by bonding a Nb foil to a Cu substrate wedge or by depositing a Nb surface on the Cu substrate. The segments are assembled with an arrangement of locking rings and alignment pins, with a controlled narrow gap between segments over much of the arc-span of adjoining segments. A tubular channel is machined in the mating surfaces of the Cu wedges. Dipole modes are suppressed by locating along each channel a tube coated with rf-terminating ferrite. A first model of the cavity is being built to investigate mode structure, evaluate alternatives for the Nb surface fabrication, and develop assembly procedures.

## INTRODUCTION

One of the dominant costs for superconducting linear colliders is the main accelerating cavities. After four decades of development, major advances have been made allowing the routine delivery of cavities with accelerating gradients approximately 30 MV/m. Fabrication of these cavities starts with sheets of Niobium. These sheets, generally with RRR greater than 200, are formed into half cells. These cells are figures of revolution from the view of a beam. These are then e-beam welded together to form a 9-cell string.

The welds merge the cavities together at the worst locations possible: the equator and the iris. The equator is the location of the highest surface magnetic field and the iris is the location of the highest electric field when the cavity is operating in the $TM_{010}$ mode. The welding locations are also the locations of the thermal breakdown and field emission. The source of the defects (such as pits, contamination, impurities, surface topology, and grain irregularities) causing these phenomena is still heavily investigated.

Several of these cavities have the capability to be used in the next generation linear collider, the ILC. However, the percentage of cavities that would meet the 35 MV/m design specification is well below 95%. The national labs would be unable to produce the quantity of cavities required within the time constraints, therefore industry must be incorporated. The industrial average is even less than the national labs, therefore something must change. The polyhedral cavity was designed to increase the success average and ease the manufacturing.

The polyhedral cavity attempts to accomplish these goals by using the concept of interchangeable parts, and an open geometry. The entire cavity can be fabricated, cleaned, polished, etched, and inspected in an open geometry allowing direct access to the superconducting surface. If one slice of the polyhedral is bad, that leaf can be replaced by another, reducing the losses to a fraction rather than reprocessing the entire cavity. The open geometry also allows for the internal suppression of HOMs and wakefields, which would improve the beam dynamics. This would also potentially allow the reduction of the iris, increasing the accelerating gradient. The most significant contribution is the direct deposition of advanced superconducting surfaces, which can provide higher gradient and Q than what is possible with Nb.

## POLYHEDRAL FABRICATION

The fabrication procedure for manufacturing a 9-cell TESLA shaped polyhedral cavity is shown in Figure 1. In this model the basic unit is a 30 degree wedge of solid copper. The copper blocks' 30 degree angles and TESLA contour are machined to the correct size by EDM which provides extremely tight tolerances. Cooling channels are gun drilled the entire length of the copper wedge providing a closed circuit plumbing system, by passing the pool cryostat code. Arc slots and radial pins are placed into each end of the wedge to confine and precisely align the 12 wedges together into a singular cavity.

Each side face of the wedge has a channel and slot machined into it providing the slot coupling and termination of the HOMs. These modes are terminated on a resistive tube lying in the machined channel. The tube, made of a material such as a nanogranular film of CoFeB–$SiO_2$ which is both resistive and permeable, has 50 K He flowing through it to remove the dissipated energy at a higher reservoir temperature, bypassing a large heat load on the SFHe circuit.

A Nb/Cu laminate foil forms the inner superconducting surface. These foils can be created by a variety of methods such as explosion bonding, deposition, or 60% reduction by cold rolling. Each of these methods should provide the necessary metallurgical bond between the foils.

The foil is formed in the correct contour and a precision dye is used to form the foil into the slot and channel on the side face. The laminate is then bonded to the copper wedge by solid-state diffusion bonding, or the foil is compressed against the copper substrate and baked in a vacuum furnace. This should eliminate discontinuities and porosity, and provide excellent heat transfer.

Once twelve wedges are completed the resistive dampers are inserted and the twelve are locked in place using two precision rings and a set of dowel pins that also align the wedges. The refrigeration circuit lines are then inserted in the gun drilled channels. The EDM tolerance

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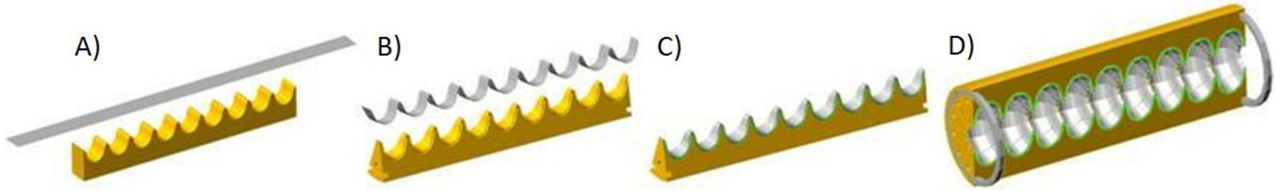


Figure 1: Fabrication of a Polyhedral Cavity: A). A block of OFHC copper and a thin foil of Nb backed with copper. B). The copper wedge is EDM machined to the TESLA contour. The foil is then stamped into the TESLA contour. The copper then has the slots, dowel holes, cooling channels, couplers, and 30 degree angles machined out. C). The foil is then stamped onto the copper wedge, using a three piece dye to ensure the edges of the slot are rounded appropriately and foil is placed in the coupler troughs. The wedge is then baked to enhance the bond between the copper backed foil and the copper wedge. Then the HOM coaxial is inserted across the length of the wedge. D). Twelve of the wedges are then assembled and the positioning rings and dowels are inserted to complete fabrication.

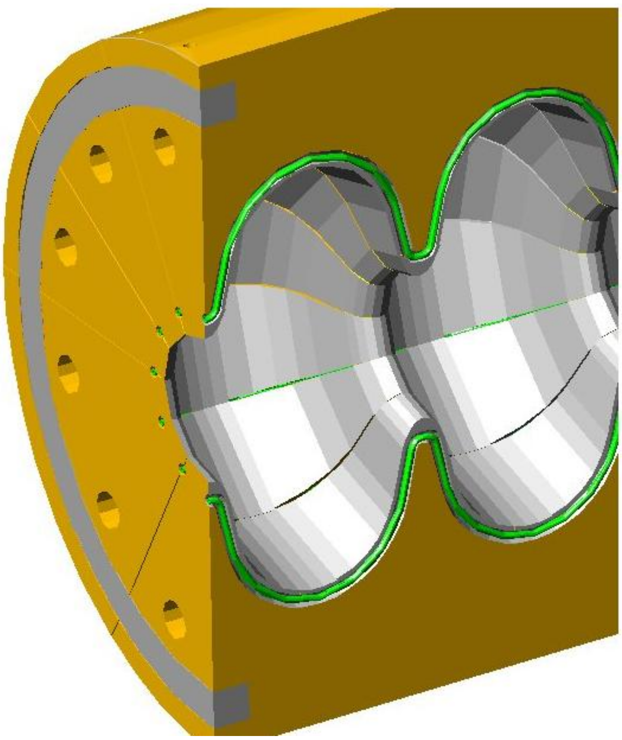

Figure 2: End view of a TESLA nine cell string illustrating the alignment mechanisms (metal ring and dowel pins), cooling channels, inner conductor, slot, and resistive tubing.

should make the cell to cell tuning quite easy using a set of screws on the back side to slightly modify the shape. The solid backing should negate the effects of Lorentz detuning, reducing cost.

These innovations tremendously reduce the complexity of the fabricating a nine cell cavity. The slot between the individual wedges has the prospect of a natural means of suppression of deflecting modes and wakefields. The open geometry allows one to clean and characterize the inner surface as well as allow the deposition of advance superconductors.

## RESONANT MODES

The two major modes of interest are the accelerating mode, or $TM_{010}$ mode, and deflecting modes, the dipole modes. The accelerating mode's currents flow parallel to the beam line and therefore the mode is insensitive to the slot between the joint created by the wedges. The slots must be narrow enough, 1 mm or narrower, and have rounded edges to not have field leakage or field enhancement on an edge.

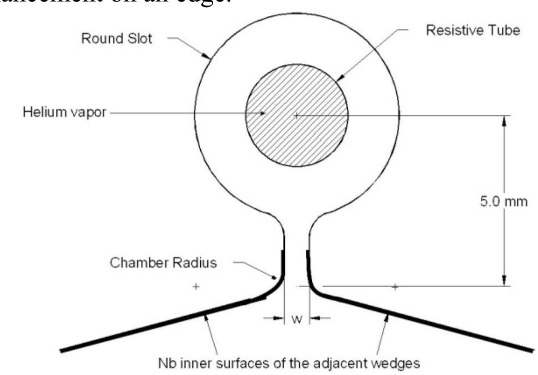


Figure 3: Cross section of the slot and resistive tube

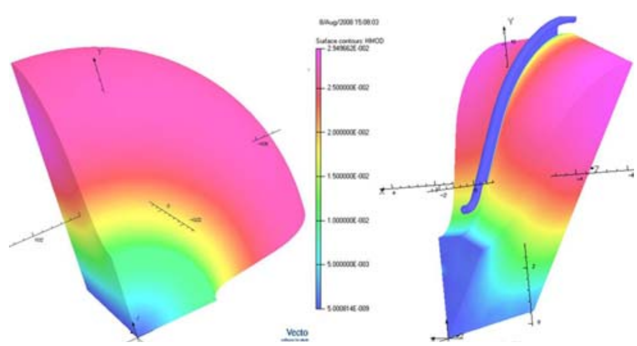

Figure 4: Left: Image of TESLA shaped cavity operating in the $TM_{010}$ mode Right: Polyhedral Cavity with a 1 mm slot operating in the same mode. The degradation to the Q is minimal even at this gap width.

The field of the accelerating mode exponentially decays into the gap: $H = H_0 e^{-\pi x/w}$ and after only $x$=.6 mm in the gap, the nominal value of the field at the opening of the slot will be reduced by half. Here $x$ is the depth into the gap, $w$ is the width of the gap, and R is the radius of curvature on the slot entrance, see Figure 3. This gap is therefore self-protecting against surface breakdown. If the Nb continues for a distance equal to the slot width ($x$=$w$), a Q of $10^{10}$ for the TESLA cavity would be decreased by less than 10% in the polyhedral shape. Thus a choice $R$=$w$= 0.75 mm, $x$ = 5 mm should produce no degradation on the Q of the accelerating mode compared with a TESLA cavity, see Figure 4.

The deflecting modes on the other hand are tremendously suppressed. The currents in these modes travel azimuthally, and therefore the slots allow the currents to down it to the resistive load. Using the same model, Figure 5, the first order deflecting mode has a Q $=3.74*10^{10}$, but in the polyhedral cavity the Q is $3*10^4$. This case uses a nanogranular film of CoFeB–$SiO_2$, in which the silica is dispersed in the ferrite to control the microstructure, which has the following properties: $\rho = 10^{-6}$ $\Omega$m, $\mu = 13\ \mu_0$, and skin depth $\delta$ of 3 $\mu$m [1]. This resistive coating on the tube also pulls the heat generated out at a warmer reservoir temperature removing the heat load on the SFHe circuit.

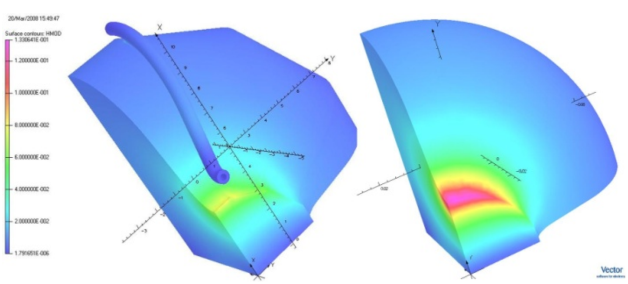

Figure 5: The first order deflecting mode in the polyhedral case and the TESLA case. The energy is coupled out through the slot to the resistive tube.

A related cavity development, the slotted cavity, was built and tested 20 years ago at DESY [2]. Slots were cut into the walls of a TESLA-like cavity in hopes to suppress dipole modes without harm to the accelerating mode. But the base structure was cylindrical, and so there was no power-law suppression of fields at the slots, so the accelerating mode Q was spoiled. The polyhedral cavity benefits from the natural suppression of fields at the internal wedge corner to escape this problem.

Independently from the Texas A&M group, the collaboration at CERN working on the Compact Linear Collider (CLIC) developed a polyhedral cavity to act as a transformer. Their PET cavities pull energy out of a high current beam and funnel it to power an accelerating cavity driving a low current beam. These copper cavities share much of the same design as our superconducting cavities in that they are able to suppress higher order modes and wakefields [3].

This cavity has a similar fabrication process but with slight variations. First the copper is made of copper and therefore is water cooled; allowing them to dump their HOM load at room temperature yet must be leak tight. The tolerances on these cavities are extremely fine, an order of magnitude less than the superconducting polyhedral cavity, yet they have achieved good results.

The polyhedral cavity has significant benefits for the beam dynamics as well as reduction in cost using interchangeable parts. It integrates many solutions to currently known problems though the simplicity of the design. This design has been confirmed to work to some level through fellow scientists work, and the open geometry allows the inspection of critical inner surface, but for the first time give the SRF world a chance to use the future of SRF, thin films.

## ENHANCED SUPERCONDUCTORS

The flat laminate superconducting foils are the perfect substrate to deposit heterostructures of Type II superconductor and insulators. These thin films were theorized by Gurevich to enhance the capabilities of the bulk superconductor by effectively shielding it from the surface magnetic field [4]. Alternating thin films of dielectric ($Al_2O_3$ for instance) and type-II superconductors, with Tc>Tc Nb and Bc>Bc Nb (e.g. NbN, Nb3Sn), are sputtered onto a Nb cavity surface, each layer's thickness being small compared to the penetration depth (~50 nm Nb3Sn, ~20 nm NbN). In that case each Nb3Sn layer should shunt ~200 mT of field, and it should be possible to double the gradient and quadruple Q compared to pure Nb. A test cavity has been designed to test wafer samples of such heterostructures [5]. If that initial development is successful, sputtering and characterization of heterostructures should be feasible in the open geometry of the polyhedral segments.

## CONCLUSIONS

- All cavity fabrication is done within common precision machining tools with common materials in an open geometry, simplifying characterization, assembly and alignment.
- Dipole modes and wakefields can be strongly suppressed internally and not affect the accelerating gradient, as illustrated by the CLIC group.
- The polyhedral structure allows for the first time the use of advanced superconductors to push gradient and Q beyond the limits of Nb.
- Funding has been received to create a single cell polyhedral cavity, and if successful manufacture a 9-cell version in the next year.

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