PROJECT DESCRIPTION
FY2006 ILC University Accelerator R&D
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Weld-Free Multi-Cell SRF cavity Development for the ILC

Personnel and Institution(s) Requesting Funding

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Project Overview

To reduce fabrication costs of the ILC elliptical superconducting accelerating structures by as much as 50%, the development of weld-free cavities is proposed.

Summary

Evaluation of alternative engineering solutions that will improve performance, decrease risk, and/or reduce cost is a standard element of any project such as the International Linear Collider (ILC). The superconducting accelerating structures of the ILC require exotic materials with technically challenging and labor-intensive fabrication processes, including special machining requirements and electron-beam welding. These techniques increase project cost because they are expensive and time-consuming.

To reduce fabrication costs of the ILC elliptical superconducting accelerating structures, the development of weld-free cavities is proposed. Seamless tubes will be produced using extrusion or dynamic flow forming techniques. The tubes will then be formed into the multi-cell shape using hydro-forming and swaging both well known industrial techniques used to fabricate shapes from tube or plate material. By utilizing these technologies, a single seamless niobium tube could be formed into a complete cavity in one or two steps.

Production of 1.3 GHz and 2.45 GHz cavities will be studied. The higher frequency decreases the cavity's overall size and allows the procedures to be developed more quickly and cost-effectively. Fabrication of similar cavities using this technique has been achieved and has demonstrated good performance [1]. The initial prototyping will be done using copper, followed by high RRR niobium. By using the proposed techniques, it is estimated that the cost of ILC's elliptical accelerating structures could be reduced as much as 50 %. The proposed study will be conducted at the NSCL over a period of two years at a budget of 710 $k.

1. Introduction

As with any project, a key element to its success is the engineering R&D that seeks to improve performance, decrease risk and/or reduce cost. The linacs for the ILC are presently designed using superconducting radio frequency (SRF) technology for acceleration. The SRF accelerating structures are expensive because of the cost of the high RRR niobium and the special machining and welding (electron-beam) steps required. To reduce costs, the development of a weld-free, multi-cell cavity is proposed.

The three areas that will be developed are tube fabrication, tube hydro-forming, and tube swaging. All these techniques are well known US industrial technologies and are currently applied to a wide range of materials. This proposal lays out a path to develop weld-free multi-cell cavities by starting with a single seamless tube and deforming it into the required shape using hydro-forming and swaging technologies. Figure 1 shows the proposed steps to fabricate a weld-free multi-cell cavity.

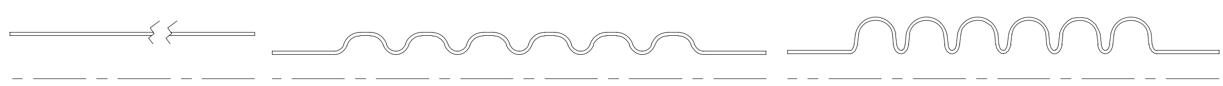


Figure 1. Fabrication steps of weld-free multi-cell cavity.

The standard technology of machining and electron-beam welding to manufacture SRF cavities is well proven. This technique uses deep drawing to produce half-cells or “cups” that are then machined and electron-beam welded. Machining and electron-beam welding make-up ~85% of the total manufacturing costs using this standard approach [2] and eliminating these steps will lead to a large cost savings. Hydro-forming and swaging companies have produced components such as large bellows that have a geometry similar to the elliptical SRF cavities. Flow forming companies fabricate seamless tubes in long lengths from materials such as titanium and refractory metals for such applications as flagpoles.

We propose to develop the fabrication process for SRF cavities with operating frequencies of 1.3 GHz and 2.45 GHz. The 1.3 GHz is the proposed operating frequency of the ILC’s linacs. The 2.45 GHz frequency will allow the initial prototyping for about a third of the cost of the 1.3 GHz cavity since the length and circumference are about half the size. The 2.45 GHz size promotes the use of the existing TELSA beam tube for the initial starting tube. These tubes are presently being supplied using seamless extrusion. Once prototyping of the 2.45 GHz structure is completed, engineering parameters obtained will be scaled appropriately for the 1.3 GHz frequency structure and provide the initial parameters for the 1.3 GHz fabrication development.

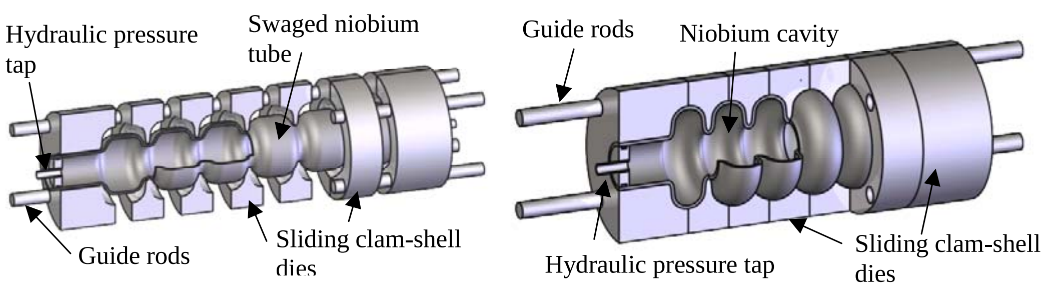
2. Tube Fabrication

The present technique for producing long niobium tubes uses sheet material that is rolled and pressed into the design tube diameter. Once the sheet material is formed, the seam is accomplished by electron-beam welding. Though this is a proven technology, it requires the expense and time of an electron-beam welder. Furthermore, to retain the formability properties of the niobium, a post annealing treatment may be required.

Short niobium beam tubes have been produced in industry using extruding and spinning. These techniques can also be applied to produce tubes in longer lengths, required for hydro-forming. Though costly for small quantities, extrusion should be inexpensive for mass production runs. Another technology that shows merit in producing long seamless tubes is Dynamic Flow Forming that combines the extruding and spinning techniques and is used in commercial manufacturing.

3. Hydro-forming and Swaging

Hydro-forming is an industrial technique used to fabricate shapes from tube or plate material. By using an internal and/or external die, the material can be formed into the design shape. Figure 2 shows a conceptual hydro-forming set-up with swaged tube where a seamless tube is set-up with a clamshell assembled external die around the tube's outer diameter. Pressure is applied to the interior surface of the tube, hydraulically deforming the tube to the die shape. An additional axial force is applied along the longitudinal axis of the tube. By supplying an axial force, the tube is compressed above its yield strength, allowing the material to "flow" into the design geometry. Figure 3 shows a stainless steel hydro-formed bellows, resembling the multi-cell elliptical SRF structure.



Hydro-forming setup of swaged tube **Cavity after hydro-forming**

Figure 2. Conceptual hydro-forming set-up with swaged tube.

Figure 3. Hydro-formed stainless steel bellows, 2.75" minor radius, 4.25 " major radius.

The ratio of the maximum radius to minimum radius is a key engineering parameter for hydro-forming. As the ratio increases, wall thinning and microcracking become more pronounced. As consequence a smaller radius ratio of 2.16 (r_E/r_I =0 2.36”/1.1”) will be used for the first stage of development at 2.45 GHz. The final goal will be procedures appropriate for the 1.3 GHz cavity radius ratio of 3.2 (r_E/r_I = 4.17”/1.31”).

Prototyping will begin with annealed oxygen free high conductivity (OFHC) copper. Annealed OFHC copper’s yield stress and Young’s modulus are similar to niobium, and will allow the first steps to be investigated at a modest cost. Once the copper hydro-forming procedures have obtained the necessary shape, the same dies and parameters will be applied to a niobium tube of equal dimensions.

Swaging is a technique were mechanical rollers are forced onto the outer diameter of a tube to reduce or neck the diameter. The deformation can be applied over a small area or along a desired length. Swaging can be used to reduce the thinning of the walls by reducing the total deformation of the hydro-forming process. The swaging reductions will be positioned longitudinally so the hydro-forming operation, which includes axial compression, will deform to the final designed shape. This will allow a larger starting tube and reduce the total material elongation performed by the hydro-forming. The swaging can also be applied to both end tubes, reducing the aperture and required initial tube length. Figure 4 shows a copper tube that has radial “grooves” and a reduced diameter, produced using swaging technology.

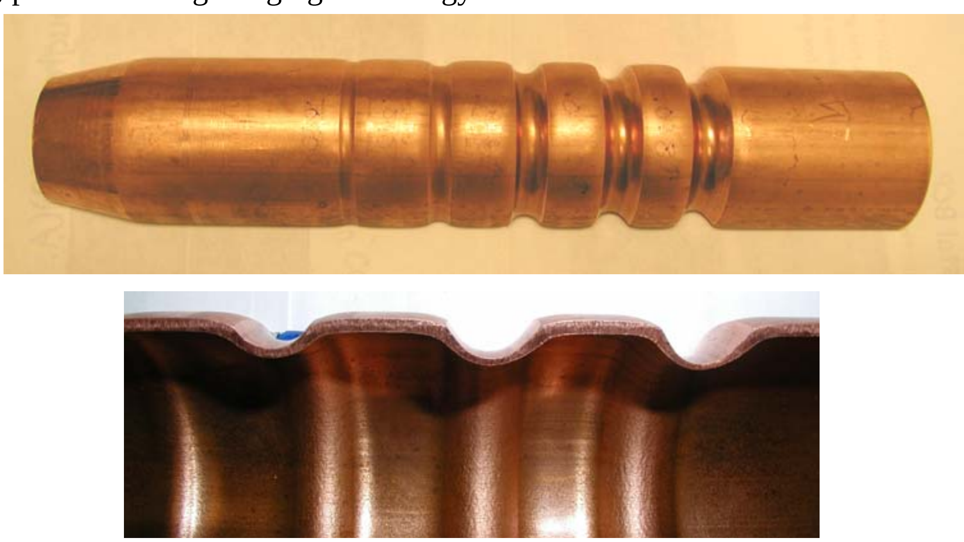


Figure 4. Upper: Copper tube with swaged radial grooves and necked diameter. Lower: Cross section of the swaged tube.

The starting tube dimensions will be optimized based on the amount of deformation determined to be achievable from the hydro-forming and the need for an initial swaging step to reduce wall thinning. The ideal hydro-forming condition is to start with a tube diameter equal to the beam tube design. As the initial swaging step is investigated, a starting tube dimension between the beam tube and cavity diameter will be required. This intermediate diameter reduces the deformation requirements of the hydro-forming and wall thinning. A swage would be applied to the position that would become the irises of the final cavity. The spacing of the swages would be determined by the amount of needed material to hydro-form to the external die design. An additional swaging step would be applied to the end tubes to “neck” them to the designed beam aperture.

Broader Impact

Development of the weld-free multi-cell cavity technology will allow the ILC and future accelerators to be constructed at a reduced cost and time scale. Initiating the development in already existing industries lays the path for the mass production of the accelerating elements, once a major project is under construction. By stepping through the learning process with direct involvement with industry, the companies will gain the experience and confidence to produce and stand behind these high-tech accelerating structures.

Results of Prior Research

Seamless cavities have been studied in other laboratory settings, and have shown success. W. Singer (DESY) has explored the Hydro-forming/Swaging concept in detail [1]. Using a scaled version, Singer was able to construct a multi-cell hydro-formed cavity, by piecing three sections together. By using Singer’s groundwork, and the many years of experience in the US hydro-forming industry, cavities can be fabricated in mass qualities, under an industrial setting.

Facilities, Equipment and Other Resources

This project can be completed using the existing facilities and infrastructure at the National Superconducting Cyclotron Laboratory (NSCL). The NSCL facilities include an electronics shop, fully integrated mechanical design department and machine shop, cryogenics plant (1.75 KW), computer department, welding department and fabrication and assembly group. The superconducting radio frequency group at the NSCL has additional specialized facilities to manufacture, process, and test the superconducting cavities. The infrastructure includes a class 100 and a class 10,000 clean room, ultra pure water system (>17 MΩ·cm), chemical etching facility with 500 CFM scrubber, sub atmospheric pumping system (< 4 K), shielded (magnetic and radiation) vertical test Dewars, and RF testing equipment.

FY2006 Project Activities and Deliverables

A copper prototype of the 2.45 GHz cavity will be completed and engineering forming parameters obtained. Using the gained engineering parameters, fabrication of a 2.45 GHz niobium cavity will follow. As prototype niobium cavities are fabricated, a material science investigation will be performed looking at thinning issues, surface roughness, RRR values, and texture measurements. All research and results will be documented and presented at appropriate venues.

FY2007 Project Activities and Deliverables

Performance testing of the 2.45 GHz niobium cavities will begin, including chemical processing, high pressure rinsing, cleanroom assembly, and vertical cold tests. A Design study will be completed, applying engineering forming parameters to the 1.3 GHz TELSA cavity design. A copper prototype cavity will be fabricated to verify parameters. Using these scaled parameters, 1.3 GHz niobium cavities will be fabricated. Material science and performance testing will be done on the 1.3 GHz fabricated well-free multi-cell niobium cavities. All research and results will be documented and presented at appropriate venues.

FY2008 Project Activities and Deliverables

All research activities shall be completed by this year.

Budget Justification

	FY06	**FY07**
2.45 GHz Prototype		
2.45 GHz Copper		
Design	.07 FTE	
Tube material	5 k	
Swaging		
Equipment	5 k	
Service	5 k	
Design	.07 FTE	
Eng	.1 FTE	
Hydroforming		
Equipment	5 k	
Service	5k	
Design	.07 FTE	
Eng	.1 FTE	
Niobium Tube Prototyping		
Niobium Material	50 k	
Design	.13 FTE	
Eng	.13 FTE	
Service	15 k	
2.45 GHz Niobium		
Swaging		
Equipment	2 k	
Service	3 k	
Design	.07 FTE	
Eng	.1 FTE	
Hydro-forming		
Equipment	2 k	
Service	3 k	

- Design .07 FTE
- Eng .1 FTE
- Finish Cavity
  - Flange material 2 k
  - Design .07 FTE
  - Flange mach. .01 FTE
  - Welding .01 FTE
  - Freq, tuning, FF .1 FTE
- Material Science (thinning, SR, RRR) .2 FTE
- Vertical Testing .24 FTE

1.3 GHz Prototyping

- Engineering parameters .15 FTE
- 1.3 GHz Copper
  - Design .06 FTE
  - Tube material 5 k
  - Swaging
    - Equipment 5 k
    - Service 5 k
    - Design .06 FTE
    - Eng .1 FTE
  - Hydroforming
    - Equipment 5 k
    - Service 5 k
    - Design .06 FTE
    - Eng .1 FTE
- Niobium Tube Prototyping
  - Niobium Material 50 k
  - Design .06 FTE
  - Eng .05 FTE
  - Service 10 k
- 1.3 GHz Niobium
  - Swaging
    - Equipment 2 k
    - Service 3 k
    - Design .06 FTE
    - Eng .1 FTE
  - Hydro-forming
    - Equipment 2 k
    - Service 3 k
    - Design .06 FTE
    - Eng .1 FTE
  - Finish Cavity
    - Flange material 2 k
    - Design .06 FTE
    - Flange mach. .01 FTE

Welding		.01 FTE
Freq, tuning, FF		.1 FTE
Material Science (thinning, SR, RRR)		.15 FTE
Vertical Testing		.25 FTE
Analyze and document results	.15 FTE	.15 FTE
Materials and supplies	5 k	5 k
Travel	5 k	5 k
Subtotal manpower	1.55 FTE	1.93 FTE
Subtotal manpower	218.55 k	272.13 k
Equipment	71 k	71 k
Service	31 k	26 k
Materials, supplies and travel	10 k	10 k
TOTAL	331 k$	379 k$

FY06-FY08 TOTAL 710 k$

Three-year budget in then-year k$

Item	FY2006	FY2007	Total
PI/Senior Personnel	$0	$0	$0
Other Professionals	$68,101	$92,375	$160,476
Graduate Students	$21,395	$22,037	$43,432
Undergrad Students	$8,840	$9,105	$17,945
Total Salaries and Wages	**$98,336**	**$123,517**	**$221,853**
Fringe Benefits	$27,730	$38,852	$66,582
Total Salaries, Wages and Fringe Benefits	**$126,066**	**$162,369**	**$288,435**
Equipment	$71,000	$71,000	$142,000
Travel	$5,000	$5,000	$10,000
Materials and Supplies	$36,000	$31,000	$67,000
Other direct costs	$7,805	$8,429	$16,234
Total direct costs	**$245,871**	**$277,798**	**$523,669**
Indirect costs (1)	$85,204	$101,168	$186,372
Total direct and indirect costs	**$331,075**	**$378,966**	**$710,041**

References

[1] W. Singer, “Seamless RF Cavities”, Proc of the 12th Workshop on RF Superconductivity, Ithaca NY (2005).

[2] D. Proch, “Industrial involvement in planning for X-FEL (TESLA)”, Proc of the 12th Workshop on RF Superconductivity, Ithaca NY (2005).