# SUPERCONDUCTING SUPER COLLIDER LABORATORY COUPLED-CAVITY LINAC MECHANICAL DESIGN

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## Abstract

A collaboration between the Superconducting Super Collider Laboratory (SSCL) and the Los Alamos National Laboratory (LANL) for the engineering and mechanical design of the SSCL Coupled-Cavity Linac (CCL) has yielded an innovative example of the well known side coupled-cavity type of linear accelerator. The SSCL CCL accelerates an H- beam from 70 MeV to 600 MeV with an rf cavity structure consisting of eight tanks in each of nine modules for a total length of about 112 meters. Magnetically-coupled bridge couplers transfer rf power from tank to tank within a module. A single rf power input is located at the center bridge coupler of each module. The bridge couplers permit placement along the beam line of combined function focusing/steering electromagnets and diagnostic pods for beam instrumentation. Each tank and bridge coupler is rf frequency-stabilized nominally to 1,283 MHz by water pumped through integral water passages. Air isolation grooves surround the water passages at each braze joint so that water-to-vacuum interfaces are avoided. Each tank is supported by adjustable spherical-bearing rod-end struts to permit alignment and accommodate thermal expansion and contraction of the rf structure. Tank struts, electromagnet/diagnostic pod support frames, vacuum manifolds and utilities are all mounted to a girder-and-leg support stand running the full length of the CCL.

## Coupled-Cavity Linac

The Coupled-Cavity Linac (CCL) is the fourth and final accelerator of the SSCL Linac. An H- beam from the Drift Tube Linac (DTL) enters the CCL at an energy of 70 MeV. The CCL efficiently accelerates the beam to an energy of 600 MeV. From the CCL, the beam travels through the CCL Transport Line to the Linac - Low Energy Booster (LEB) Transfer Line to the LEB.

The SSCL CCL consists of 72 side coupled-cavity tanks. Each of nine modules contains eight tanks, and each tank increases in length as the beam energy increases. The 63 magnetically-coupled bridge couplers, seven per module, also increase in length, except for a length adjustment after CCL Module 2. Each module is independently powered, with no bridge coupler spanning the tanks between modules. Basic design parameters are defined in Table 1.

TABLE 1
Basic Rf Structure Parameters

| | |
|---|---|
| Structure Type | Tanks, side-coupled.<br>Bridge couplers,<br>magnetically-coupled |
| Frequency | 1283 MHz (nominal) |
| Rf Peak Power | 15 MW |
| Rf Pulse Length | 60 microseconds |
| Repetition Rate | Single shot to 10 Hz |
| Tank Rf Power Dissipation | 1 kW |
| Module Water Flow | $23 \times 10^{-4}$ $m^3$/sec (36 gpm) |
| Structure Operating Temp. | 40.5 °C (nominal) |
| Design Vacuum Level | $8 \times 10^{-6}$ Pa ($6 \times 10^{-8}$ torr) |

## Rf Structure

SSCL and LANL personnel have performed rf structure and support systems engineering analyses and developed mechanical design interfaces between the CCL rf structure and the CCL support systems such as the support stand, vacuum manifold and Linac utilities.

### Rf Structure Design

Since the tank and bridge coupler lengths increase along the CCL, the detail design drawings of the rf structures are being prepared by LANL using a design tool called Graphics Interactive Programming (GRIP). The first tank and bridge coupler are drawn using traditional CAD techniques. The GRIP program then automatically generates new drawing sheets for each subsequent tank and bridge coupler by reading an input file containing those dimensions which change according to beam physics and energy level.

The most basic unit of the CCL tank rf structure is the monolithic half-cavity. The monolithic style was selected on the basis of several advantages. The small size of the 1283 MHz rf structure simplifies lathe and mill machining of the tank half-cavities. The monolithic style also requires fewer, less complex braze joints than other construction methods. The bridge couplers are even simpler, consisting of cylinders and disks brazed together with monolithic end cells. The parent material of the CCL tanks and bridge couplers is OFE copper per ASTM F68, Class 2 or better, selected for its high electrical conductivity and compatibility with hydrogen brazing processes. The material can be procured in either cross-grain forged or plate stock raw forms.

The tank and bridge coupler rf cavity outer profiles are dimensioned and toleranced to allow the copper supplier to pre-

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machine the outer perimeter of the cavities and supply them ready for rough machining of the physics dimensions. Tank half-cavity body height is identical throughout the CCL for uniformity of support stand and vacuum manifold design. Tank end cell and bridge coupler height must be identical throughout the CCL due to the fixed height of the beam line components under the bridge couplers of each module.

The shape of the tank and bridge coupler rf cavities permits use of integral water passages for frequency stabilization of the rf structure. Of the water passage designs considered for this CCL, integral water passages are the simplest, the cheapest to manufacture and have the best thermal characteristics. With integral water passages, however, all types of corrosion must be inhibited over the 25-year minimum operating service life of the CCL. Materials selection (gold/silver/copper braze alloys and copper parent material) is an important factor inhibiting galvanic corrosion in low conductivity water. Also, the water velocity is selected to minimize both pitting corrosion and erosion in the water passage walls. A stated requirement to avoid any water-to-vacuum braze joints led to the use of air isolation grooves machined concentric to the integral water passages of the tank half-cavities and diagonally across the corners of the bridge coupler cavities. When stacked for brazing, each of the four water-to-vacuum interfaces in the braze joint is isolated with a band of air. These "weep holes" ease the task of isolating water leaks in the integral water passages or vacuum leaks in the tank accelerating cell and bridge coupler cells.

Slots milled in the tank and bridge coupler cavity sidewalls permit tuning the cavities by dimpling the copper wall in the bottom of the slots. Precision holes are machined in the corners of the cavities for stainless steel alignment dowel pins. Two of these holes are used for cavity alignment during tuning, and two are used to maintain cavity alignment during brazing. The pin holes are oriented symmetrically and hold the pins with a relatively loose fit to prevent binding during brazing.

An important factor in the rf structure design is the selection of braze alloy form and composition. All of the tank and bridge coupler braze joints use a foil braze alloy to ensure full joint wetting for high strength and vacuum integrity. Step brazing processes influence the selection of alloy composition, which in turn determines braze joint design. For any particular tank, the first braze joins two half-cavities at a braze joint designed for a braze alloy thickness after brazing of 0.05 mm. While the alloy composition for this step has not yet been selected, both 50% gold - 50% copper and 80% gold - 20% copper foil alloys retain their thickness after brazing, and either could be used in this joint. The stack braze which joins pairs of half-cavities with end cells for a full tank requires a 72% silver - 28% copper foil alloy which does not retain its thickness after brazing. This braze joint design does not account for any braze alloy thickness after brazing. In general, the brazing process must be closely monitored to ensure good dimensional control and reliable, vacuum and water leak-tight braze joints.

### Rf Structure Interfaces

A vacuum nipple brazed into each tank coupling cavity allows access to the internal coupling cavity posts for tank tuning. In normal operation, the upper vacuum ports are capped and the lower ports interface through bellows to a vacuum manifold. These vacuum ports are the same height throughout the CCL to simplify support stand and vacuum manifold design. The inlet and outlet beam line vacuum flanges are a quick-disconnect style with clamp chain couplings and metal o-ring seals. These flanges are brazed into the tank as well as four rf monitor-probe interface flanges, one each on the tank end accelerating cells for monitoring magnetic fields in the tank and one each on the tank end cell coupling cavities for tuning a module with the bridge couplers in place.

An additional rectangular flange brazed to each end of most tanks and all bridge couplers mates the two rf structures. These flanges and associated seals provide both a vacuum and an rf joint. The same flange and rectangular metal o-ring vacuum seal are used for all of the CCL modules, with only the flange mounting interface differing between modules. The rf seal is a canted-wire type which can easily be custom fit to the different module tank and bridge coupler end cell rf surfaces. This tank-to-bridge coupler interface is a hard-bolted joint with no compliance other than the ability of the annealed copper tank end cell coupling cavity walls to deform. These walls have been deliberately thinned so that any tank and bridge coupler flange misalignments are accommodated by deformations in the walls. The coupling cavity can then be retuned by pushing or pulling on thread inserts located in the tank end cell coupling cavity endwalls. Four alignment target holders, brazed on the access aisle side of each tank, hold steel-ball alignment targets which permit precision alignment of the tank to the linac beam line within the required ± 0.1 mm. Lines of sight are clear to all four alignment targets from the floor monument-mounted alignment instrumentation.

### Support Systems Mechanical Design Features

The CCL rf structure is supported along the linac beam line by a series of six-strut support systems mounted on girder-and-leg support stands spliced along the full length of the CCL. Each individual stand supports two tanks, a bridge coupler, a vacuum manifold and water supply and return manifolds (see Fig. 1).

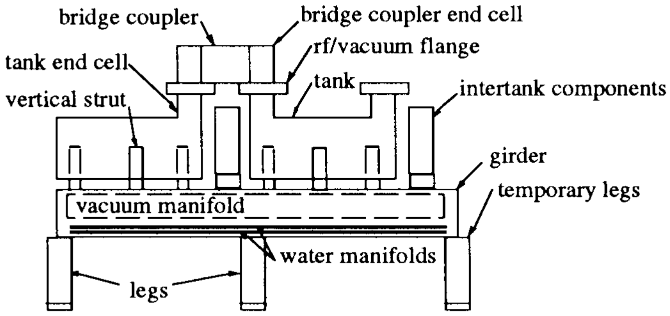

Fig. 1 Individual CCL Support Stand

Also mounted on the individual support stand are two intertank support frames holding an electromagnet, a diagnostic pod and other beam line components. All of this equipment is self-contained on the individual support stand. A set of temporary legs and casters are mounted to the support frame to facilitate handling in the laboratory and linac tunnel. After laboratory tank tuning, the support stand with its tanks, support frames and manifolds is lowered to the linac tunnel, wheeled into place and installed. The temporary legs and casters are removed, the ends of the stand are spliced onto and supported by the legs of the previous support stand and the legs are bolted to the concrete tunnel floor. Shim packs under the leg pads provide rough alignment of the girders, and the six adjustable struts provide the fine tank-to-beam line alignment necessary to install the module bridge couplers.

Individual tanks are supported on ledges machined into three tank support brackets, each of which is bolted into thread inserts in the sides of the tanks. After snugging the bracket onto the tank, two roll-lock pins are match-drilled and inserted through the bracket and into the tank to secure the bracket in place. Lifting eyes attached to the top of these brackets provide for stable lifting. The bridge couplers also have a lifting eye threaded into each end. The tank support brackets provide the interfaces for the individual struts of the six-strut support system. The three vertical struts each bolt to the mid-plane of a bracket. The two horizontal struts and the one longitudinal strut each bolt to the bottom of a bracket. The two rod-ends of each strut have right-hand threads with a different pitch permitting fine adjustments to the position of the tank. During module installation, each tank is supported and adjusted in the longitudinal direction by its own longitudinal mini-strut. This longitudinal adjustment is necessary because a dowel pin must align with dowel pin holes drilled in each tank and bridge coupler rf/vacuum flange before the bridge coupler drops onto the tank at the proper location. With the bridge couplers installed, however, the bridge couplers become the longitudinal struts and the entire module is supported longitudinally by one longitudinal strut on tank 4 or 5 of the module. Thermal expansion and contraction in the module occurs cumulatively to either side of this one longitudinal strut. The spherical bearings in the strut rod-ends permit the tanks to expand and contract as necessary without binding or stressing the rf structure. This six-strut system provides a simple tank support scheme that easily accommodates thermal expansion and contraction of the CCL modules.

The CCL tanks and bridge couplers are frequency-stabilized by pumping low conductivity water through water passages integral to the tank and bridge coupler rf structure. This frequency stabilization system maintains near-identical temperature profiles and resultant structural displacements throughout each tank and bridge coupler so that they resonate at the same frequency. A Temperature Control Unit (TCU) pumps the water through supply and return manifolds and supply and return tubing to each tank and bridge coupler. A fractional-to-metric tube connector mates the inch sized tubing to the metric female threaded ports brazed into each tank and bridge coupler. During module installation, the water supply and return manifolds on each support stand are spliced together to create common supply and return manifolds. One TCU controls the bulk water temperature within the tanks and bridge couplers of a module to within ± 0.1 °C. A temperature monitor on each end of each tank senses the rf structure temperature and sends a signal to the CCL supervisory control system, which in turn controls the TCU. The water supply and return manifolds are designed as a reverse return system. Supply water entering the first tank must enter at the end of the return manifold and flow through the entire length of the return manifold, where back pressure is sufficient to balance the water flow in the module rf structure.

During module installation, the vacuum manifolds on individual support stands are bolted together to create a common module vacuum manifold. The module vacuum manifold is supported by eight floor-mounted, 500 l/sec ion pumps. This quantity and capacity of ion pumps has been nominally specified to maintain the required vacuum level in the module. The manifold is attached to each tank by eight bellows and vacuum flange assemblies. When the manifold is evacuated, the weight of the ion pumps counters the atmospheric pressure loads tending to push the manifold toward the tanks. When the ion pumps are removed, the manifold drops to a stand web designed to cradle the manifold.

Between every pair of tanks in the CCL, a frame supports both a combined function steering/focusing electromagnet and a diagnostic pod. Extending from this package are the beam tube, two edge-welded bellows and two or more vacuum flange couplings. The bellows permit independent alignment of the intertank support frame and accommodate thermal expansion and contraction of the rf structure. Bolted to a bar spanning the longitudinal girders of the support stand, the intertank support frame provides a three-point adjustment support for fine alignment of the magnet/diagnostic pod package to the beam line. Also mounted on the beam line between modules is a vacuum isolation valve permitting replacement of beam instrumentation within a module without loss of vacuum in other modules. If a vacuum leak is detected in a module, the electro-pneumatic valve closes within one second to protect other CCL modules from contamination.

All of the support stands have the same height and width, but the length of an individual support stand is determined by the length of the tanks and bridge couplers it supports. For this reason, the CCL design team will use a GRIP program similar to that used for the rf structure to prepare the support stand and manifold fabrication drawings. The general configuration of the support stands will be replicated throughout the CCL, but the stands will be lengthened as the tanks and bridge couplers lengthen.

## Status and Schedule

The preliminary design review (PDR) of the rf structure was successfully passed on 28 April, 1992. The preliminary design requirements review for the support stand and related support systems will be held in September, 1992, and the PDR will probably be held in October, 1992.

The SSCL CCL is being fabricated by SSCL, LANL and the Institute of High Energy Physics (IHEP) in Beijing, China. The three laboratories will share CCL Module 1 construction with delivery scheduled for early 1993. IHEP will fabricate CCL Modules 2 through 9 with a phased delivery scheduled to conclude in June, 1994.