THE CEBAF CAVITY CRYOSTAT

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The modular design of the linac cryostat system based on a cavity-pair is presented. Description of the cryogenic module consisting of four cavity-pairs is included. The methods of making a cavity-pair hermetic during cryostat assembly, introducing the waveguides, supporting the helium vessels and introducing instrumentation are presented. Also included are the methods of tuning the cavities, aligning them to exterior references and connecting cryogenic fluid circuits to adjacent modules and transfer lines.

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Introduction

The CEBAF cryostat system encloses 418 of the CEBAF/Cornell cavities[(1)(2)] and maintains them at 2K. The system also positions the cavities to form the accelerator.[(3)] Four hundred cavities are used in the two linac segments and eighteen cavities are used in the injector. The system is modularized into fifty-two stand-alone cryostats called cryomodules containing eight cavities and one short cryomodule containing two cavities. The 8.4 meter long standard cryomodules (see figure 1) are further subdivided into four non-stand-alone portions called cryo-units which contain pairs of cavities (see figure 2) and into end caps which contain the utility connections for maintaining the cavities at operating temperature. Cryogens are supplied by a central helium refrigerator[(4)] and piped to the cryomodules using transfer lines. For the 2.2 K helium supply circuit and the 40 to 50 K shield circuit, the string of cryomodules acts as its own transfer line. Cryogen connections to and between cryomodules are made using U-tubes between the bayonet sockets in end caps and transfer lines. Note that heat loads are summarized in reference 4.

In the following report, we describe the system from the inside out, starting with the cavity-pair.

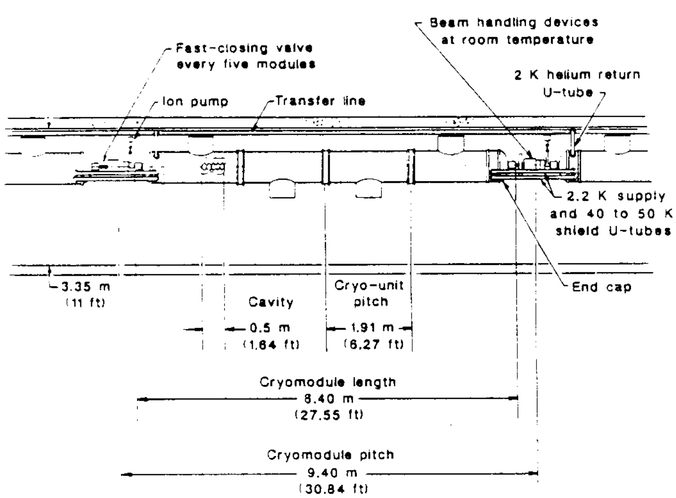

Figure 1 Schematic plan view of a cryomodule installed in the line. (RF equipment not shown.)

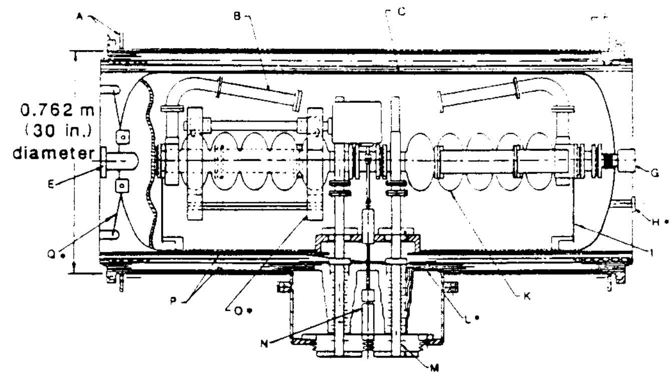

Figure 2 Top view of a CEBAF cryo-unit. Asterisked items shown only once. (A. Vacuum shell flange and captured seal ring: B. HOM load; C. Magnetic shield; E.* 2 K return helium connection and helium vessel; F. 40 to 50 K radiation shield; G.* Beam-pipe flange surface on end valve; H.* 2.2 K helium supply line; I. Outboard cavity support; K. Cavity; L.* Axial support; M. Fundamental waveguide; N. Rotary feedthrough; O.* Tuning mechanism; P. Superinsulation; Q.* Helium vessel support rod.)

Cavity-Pair

A principle recommendation of the cryostat workshop held at CEBAF on October 1 through October 3, 1985[(4)] was that superconducting RF cavities should be made hermetic while still in the clean room, immediately after final chemical cleaning. The cryostat could then be constructed around the cavity in a less clean environment with assurance that the assembly operation would not contaminate the interior of the cavities.

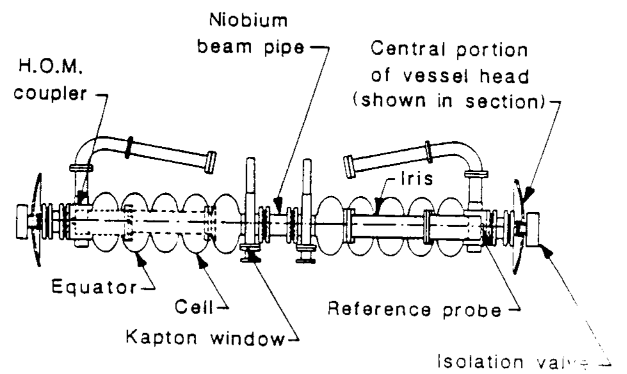

Figure 3 Cavity pair as assembled in a clean room.

Our design follows from this recommendation. The hermetic unit of two cavities is called the cavity-pair and is configured and sealed as follows. (See Figure 3.) The cavities of a cryo-unit cavity-pair are spaced with respect to each other at two and one-half cell pitches from iris to iris. At the far ends, a superconducting-to-normal, niobium to stainless steel transition is maintained at 14.0 cm from the last iris. Beyond this joint, the beam pipe contains a stainless steel hydroformed bellows before the pipe intersects a preplaced portion of the vessel head. The disk-like portion of vessel head allows the remaining ring-like portion of the head to be assembled over the gate valve. This viton O-ring sealed gate valve with all welded bonnet is the closure mechanism on the beam-pipe. The O-ring has to seal at room temperature only and tests show it survives the temperature excursion.

The higher order mode (HOM) loads that seal the ends of the waveguide stubs on the HOM coupler (and dump their heat into the helium), are non particulate producing. The remaining penetrations into the cavities are the input power waveguides, which are sealed by Kapton windows and two RF reference probe mounting holes which are sealed by their probes.

The sealing method for demountable joints involving relatively soft niobium is the Indium gasket joint used at Cornell and elsewhere. A 1.5 mm diameter Indium wire is compressed between flat flanges that are bolted and loaded with belleville springs. Before making up the joint, the Indium is laid into a triangular groove in a teflon mold and then pressed against one flange face to adhere it to the right position.

A fixture is used in the clean room to position and orient the cavities correctly with respect to their reference surfaces. After all seals are made and tested, the cavity pair is evacuated to 10^{-7} torr and the valves are closed.

Tuning Mechanism

The cavities must be tuned by physical deformation to within 20° of phase, which corresponds to 1,497.000 MHz ± 124 Hz. This is equivalent to a dimensional change range of 0.5 μm. Tuning is accomplished by attaching a stiff collar to the equators of the end cells of the cavity. A yoke, attached to one of the collars, acting on links attached to the other collar, compresses the cavity axially. The mechanical movement of the yoke is driven by a link whose length is changed by a differential screw. It is driven by a stepper motor from outside the cryostat. A worm gear reducer in the drive provides additional reduction in motion such that the cavities are tuned through the required range by turning the outside shaft through 500°. The cavities are permanently tuned to one side of the frequency range such that the tuning range is spanned exclusively by compression. This avoids an insensitive dead band around zero, where the mechanisms may have backlash.

All wear surfaces of the differential screw, gear reducer and universal joints are covered with dicronite (tungsten disulfide) solid lubricant. In addition, mating gears and threads are alternately made of stainless steel or aluminum bronze for good wear qualities. Rotary motion is transmitted from outside the two vessels by bellows-sealed, rotary feedthroughs.

A linear potentiometer for position sensing and limit switches for overrun avoidance are mounted to the differential screw.

Instrumentation

In addition to the potentiometer and limit switches listed above, the cryo-unit requires transmission of the signals from the two RF reference probes using coaxial cables and from two diodes acting as thermometers. A 10W heater for Q measurement also requires leads from the exterior. All leads into the helium vessel are conducted through ceramic feedthroughs rated for cryogenic service. All are mounted on Conflat flanges so that they may be thermally cycled and leak tested before use.

Helium Vessel

Each cavity-pair is encased within its own 316L stainless steel helium vessel. The cavities are mounted to the vessel through the power input waveguides whose flanges are bolted and sealed to the interior of the vessel near its center. Two thin, plate-like supports, mounted between the vessel and the cavity in the same orientation as the waveguides, support the far ends of the cavities radially while maintaining axial flexibility. At room temperature, the stainless steel supports are mounted so that the cavity-pair ends are deformed off axis by about 0.4 mm. Upon cooldown, the differences in thermal contraction between the niobium waveguide and the thin plate pull the cavity-pair axis into a straight line. The slight difference in contraction between the two waveguide mounts and the cavity is taken by elastic flexure of the cavity waveguides.

Tooling is used to align the cavity-pair axis with the outside cylindrical surface of the Conflat flange on the beam-pipe gate valves. These surfaces are used to align the cavity-pair at a later stage of construction. The ring-like portions of the vessel heads are welded to the shell and to the head portions on the cavity-pair valve assembly. The heads contain the 10 cm diameter tube penetrations that connect the helium vessel to others in the cryomodule or to the piping in the end cans. The demountable joint used for all low temperature, stainless steel to stainless steel connections, such as this crossover, is the Conflat flange.

Power Input Waveguides

The 2.50 cm x 13.44 cm input power waveguides are the principle penetrations from the exterior into the cryo-unit helium vessel and represent the greatest heat leak. They are constructed of .081 cm thick stainless steel with a 2 μm (several skin depths) internal copper plating. The waveguides are bead blasted on their inner surface to minimize specular reflection and have a coating of cupric oxide to raise absorption so that little radiant heat reflects to the cold end. Conduction to 2 K is minimized by a 55 K heat intercept located 8 cm from the 2 K vessel.

The waveguides terminate on the outside of the vacuum vessel in the top hat region with a flange mounted to a hydroformed bellows. The supports for the helium vessel withstand the compressive force created when the vacuum vessel is evacuated and atmospheric pressure presses on the bellows.

Thermal and Magnetic Shielding

The remainder of the cryo-unit is a shield system to prevent both heat and magnetic field from reaching the helium vessel and cavity respectively. This shield system is not complete with each cryo-unit as is the helium vessel. It is open ended, to be completed only by bridging to the next cryo-unit or an end cap. The shells of this system from the inside out are (1) the magnetic shield, (2) 15 layers of superinsulation, (3) vacuum space, (4) 40 to 50K shield, (5) 60 layers of superinsulation, (6) vacuum space and (7) vacuum vessel.

Magnetic Shield

The magnetic shield required to lower the ambient field below .005 gauss is a cylinder of nickel-iron alloy called Conetic that is .04 cm thick. These sheets are laid on the vessel lengthwise, lapped at their edges and pop riveted to form a cylinder. The gap between cryo-units is completed by pulling out overlapping sleeve-like portions of the material that are trapped at assembly between the helium vessel wall and the main shield cylinder. The hole in the cylinder for the input waveguides is closed by a similar trapped piece that can be pulled down to close the hole like a shade in an airliner window.

The cryo-unit houses part of the transfer line for the 2.2 K supercritical helium supply circuit. This lightly superinsulated pipe is located outside the magnetic shield and inside the helium vessel's superinsulation.

Superinsulation

Superinsulation is used between the 2 K helium vessel and the 40 to 50 K shield (15 layers) and between the shield and the room temperature vacuum vessel (60 layers). The insulation consists of double aluminized mylar of approximately 300 Å coating thickness and an emissivity of .03 separated by three layers of light dacron polyester netting.

Joints in the insulation are made by butting 15 layer blankets and using aluminized mylar tape to seal the outer most layer. All joints are staggered to minimize any local hot spot. The blankets between cryo-units are pre-cut oversized and are installed bunched-up to allow for shrinkage during cool-down.

40 to 50K Shield

The shield is made of 2.4 mm copper sheet brazed to an axial copper pipe. The shield is circumferentially slit for several inches on either side of the pipe, between every patch of braze to allow for dimension change during sudden cool-down and warm up. The ends of the tube are GTA welded to a short nickel tube which in turn is welded to a Conflat flange. This use of intermediate nickel between copper and stainless eliminates "hot short" cracking experienced in stainless to copper welds.

The sheet copper transmits heat leaking through the superinsulation with negligible temperature rise and acts as a distributed heat conduit for the thermal intercepts used in the supports, waveguides and instrument cables. The shield is supported radially and axially from columns of G-10 strip that are bolted tangentially to the shield and rest in sockets in the inside ends of the vacuum vessel. The hole in the shield in the waveguide region is covered by a bolt-on cover plate. The shield is joined to the neighboring shields by a copper strip that is attached to one shield and slides over the other.

Vacuum Vessel and Helium Vessel Support

The vacuum vessel housing the insulation vacuum is made of 304 L stainless steel. Large flanges on the ends stiffen the shell and provide a base for the helium vessel support rods. Flanges at the ends are machined to permit alignment of successive cryo-units by simple bolt-up of the O-ring sealed sleeves between cryo-units. The cryomodule structural frame is formed by the cryo-unit vacuum vessels and these sleeves. The vacuum vessel has a side opening called a "top hat" that permits installation of waveguides and other instrumentation devices. The cylindrical cover of the top hat is O-ring sealed to facilitate access to this region.

The liquid helium vessel is supported at each end by four stainless steel rods mounted between the helium vessel head and the inside of the vacuum vessel flange. The rods are positioned in a double-X (XX) pattern such that pitch, roll, yaw and radial translations are constrained. The mounts are such that contraction of the vessel towards center is slightly less than the graded contraction of the entire rod upon cooldown. Thus, the rods increase their state of tension. The over-constrained pattern was chosen to maintain the helium vessel centered in the vacuum vessel and to minimize the lateral strains on the input power waveguides and their joints. The rods are adjusted at assembly at each end such that the surface of the Conflat flange on the gate valves is centered with respect to the outer surface of the vacuum vessel flange. A single G-10 dog-bone shaped support provides axial support for the helium vessel. This support is located in the top hat region. All helium vessel supports are thermally intercepted from the shield using copper braid.

Cryomodules

Cryo-units are assembled into cryomodules with the top hats in a left-right-right-left pattern. The purpose of this pattern is to reduce to a negligible value the effect of small transverse beam kicks caused by the asymmetric fields in the fundamental power couplers. In addition to the hardware mentioned earlier, the connections between cryo-units utilize a beam pipe with bellows and a pinch-off pump-out tube and utilize connection pipes for the shield and 2.2 K helium flows.

A supply end cap is bolted to the vacuum vessel on one end of the cryomodule, and contains the bayonet sockets for two U-tubes, one supplying 2.2 K supercritical gas and one supplying 40-50 K shield gas. The first is internally connected through a JT valve to the input of the helium vessel in the first cryo-unit, and also continues in parallel with the JT valve into the transfer line passing through the first cryo-unit. The 40-50 K gas input is connected through a thermal shield in the end cap into the shield in the first cryo-unit. This end cap also contains all the relief valves and rupture disks on both the helium circuits and the vacuum tank. A beam-pipe extension with thermal expansion bellows and a transition from 2.0 K to room temperature is also included in this piece, as a closure for the magnetic shielding and closures for the superinsulation blankets. Vacuum vessel closure is provided by a cover which passes over a motorized gate valve located on the beam pipe.

At the other end of the cryomodule, a return end cap is similarly attached to the cryomodule, and contains bayonet sockets for three U-tubes. One of these sockets is for continuing the 2.2 K supercritical gas supply to the next cryomodule, one is for continuing the shield gas to the next cryomodule, and one is for connecting the 0.031-atmosphere helium gas exhaust line to the return transfer line. This bayonet socket contains a high vacuum valve and a helium purge and a guard vacuum anti chamber to stop contamination of the sub atmosphere helium. The components in this cap are similar to those in the supply end cap, except that the additional U-tube connection is connected into the pipe at the top of the helium vessel and contains the module's liquid-level gauge. Another exception is that the connection between the 2.2 K supply line and the liquid helium vessel is absent. Pumping ports on the insulation vacuum are provided at both ends.

Each cryomodule also has two detachable support stands cradling the vacuum vessel at the inner end of the first and fourth cryo-unit. Each stand's feet contain the adjustment mechanisms necessary to position the module on the beam-line axis.

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