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CEBAF-PR-86-010

THE CEBAF SUPERCONDUCTING ACCELERATOR CRYOMODULE

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Abstract

The design and fabrication of the cavity enclosure and calculation to support the 2°K operating temperature, and techniques for minimizing operating heat loads and cryostat loads are discussed. The integrating of the Cryogen fluid distribution system into the cavity cryostat will be presented. Integration of the cavity design into cavity fabrication and maintenance program, with emphasis on system reliability and flexibility, is included.

Introduction

The CEBAF cryostat system encloses 418 of the CEBAF/Cornell cavities[1,2] and maintains them at 2K, and also positions the cavities to form the accelerator. 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 are further subdivided into four non-stand-alone portions called cryounits which contain pairs of cavities. Cryogens are supplied by a central helium refrigerator. Cryogen connections to and between cryomodules are made using U-tubes between the bayonet sockets in the cryomodules. Figure 1 shows a tunnel view of the cryomodule.

Operating Temperature

The operating temperature of 2K was chosen because it affects the Bardeen, Cooper and Schrieffer (BCS) component of the cavity Q, and thereby the RF heat load, hence affecting the capital and operating refrigeration costs. BCS losses vary inversely with the cavity Q, approximately doubling every 0.2K. Refrigeration costs vary inversely with the temperature; in addition capital costs increase with the 0.7 power of heat load, while operating costs increase to the 0.85 power. Curves of the total heat load as a function of temperature and normalized costs are shown in figures 2 and 3. The BCS losses, while an exponential function of temperature, are still a small fraction of the total heat load at 2K and the refrigeration capital costs are flat to 0.5% between 2K and 2.2K. Calculated refrigeration loads are given in Table 1.

Cavity Pair

The challenge in constructing a superconducting RF cavity linac is to keep the interior surfaces of the cavities clean through the assembly, testing, installation, commissioning and running.

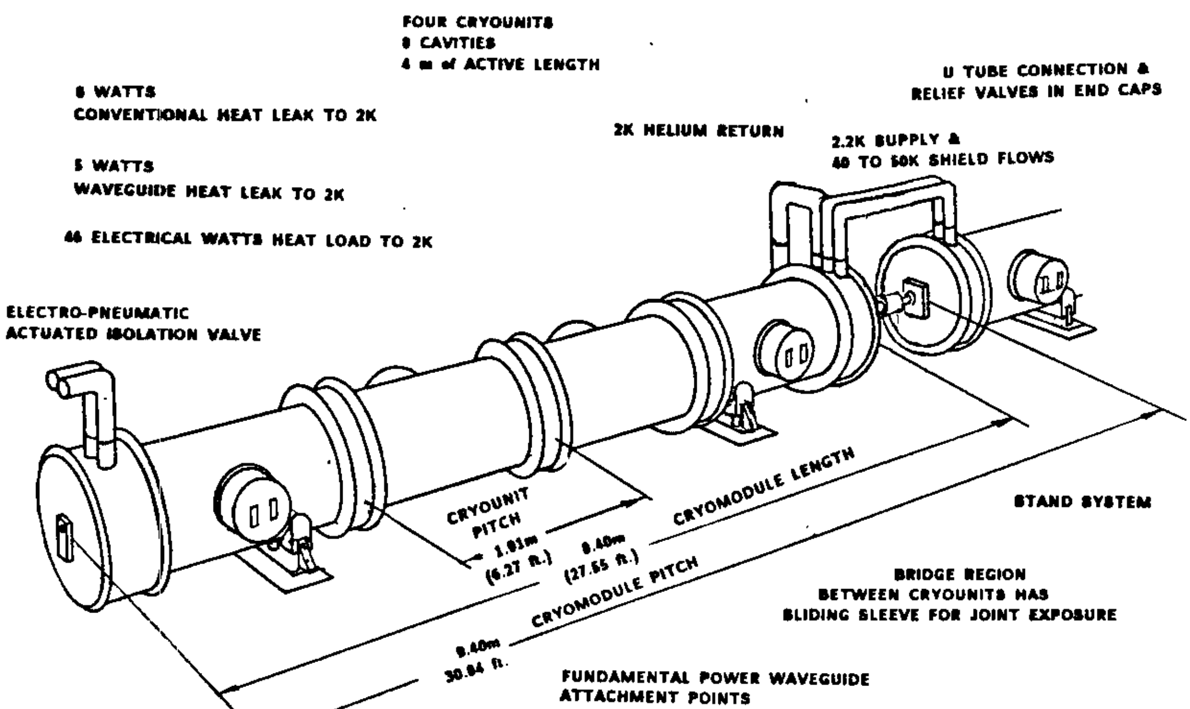


Figure 1

Table 1. Linac Heat Load Summary-418 Cavities

	Total Watts 2.0K	Total Watts 50K
418-RF Heat Loads		
RF Residual Losses	1337	-
BCS Losses	477	-
Input Waveguides	171	1129
HOM Losses	105	-
Input Waveguide Joint	79	-
Un-Allocated	231	-
Total RF Load	2400	1129
209-CRYOUNIT HEAT LOAD (Inc. Two Half Bridge)		
Radiative (MLI)	46	920
Input Waveguide	263	1714
2 K Supports	19	152
Shield Supports	-	410
Tuner	10	42
Instrumentation	42	84
Un-Allocated	59	105
Sub Total	439	3427
53-PAIR END CAPS (Inc. Set 3 U-Tubes)		
Radiative (MLI)	5	53
JT Valve	13	133
Relief Lines	13	159
Bore Tube	25	366
50K U-Tube Etc.	-	201
2.2K U-Tube Etc.	42	265
2.0K U-Tube Etc.	106	657
Instrumentation	5	10
Supports	3	27
Un-Allocated	25	37
Sub Total	237	1908
TRANSFER LINES		
Supply T. L.	2	80
Return T. L.	17	700
Injector T. L.	2	80
50K U-Tube (5)	-	19
2.2K U-Tube (5)	4	50
Shut Off Valve & Tee (53)	53	424
Junction Boxes (8)	8	80
Refrigerator Connection	38	103
Sub Total	124	1536
Total Static Heat Load	800	6871
GRAND TOTAL	3200	8000
CAPACITY WATT	4800	12,000
%	150%	150%

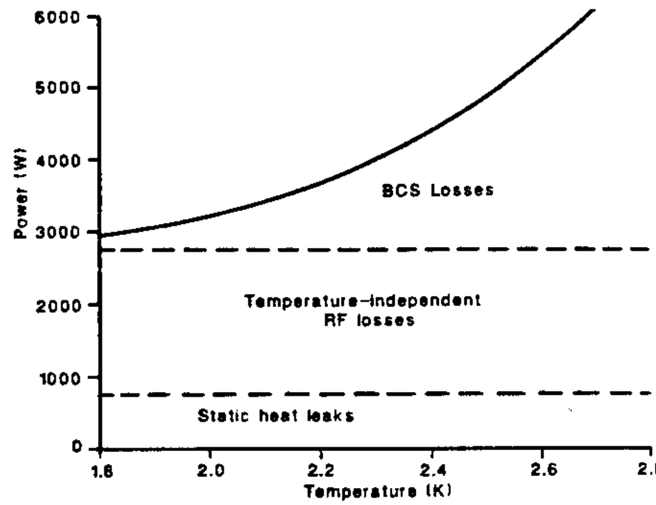


Figure 2 Total heat load as a function of temperature

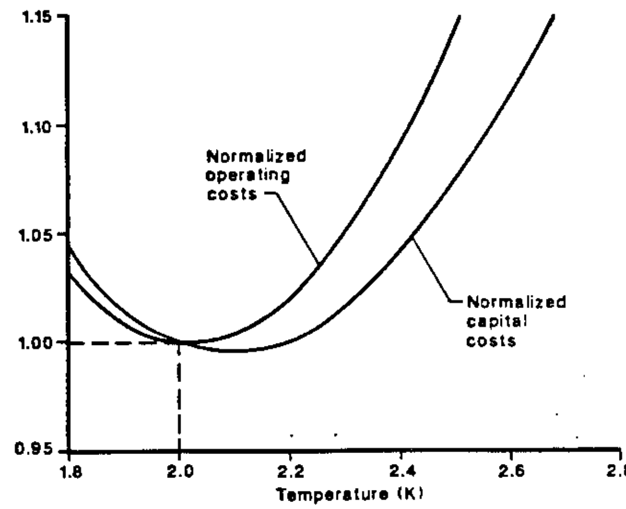


Figure 3 Normalized costs

The hardware is designed to aid in maintaining this cleanliness. The principle element of this design is the concept of the cavity pair. Superconducting RF cavities are joined and made a hermetic unit while still in the manufacturer's clean room, immediately after final chemical cleaning. The cryostat may be constructed around the pair in a less clean environment with assurance that the assembly operation does not contaminate the interior of the cavities. Figure 4 shows the configuration of a cavity pair.

The cavity pair parts are sealed to one another by indium gaskets that have been used successfully at Cornell and elsewhere. The beam tubes are closed off by O-ring sealed gate valves, and the fundamental power waveguides are sealed with kapton windows. Both have been proven suitable by tests at Cornell.[3,4]

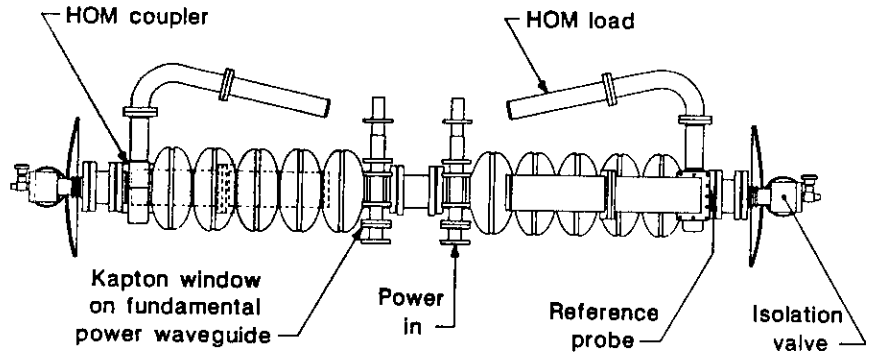


Figure 4 Cavity Pair as Assembled in Clean Room

Tuner

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.

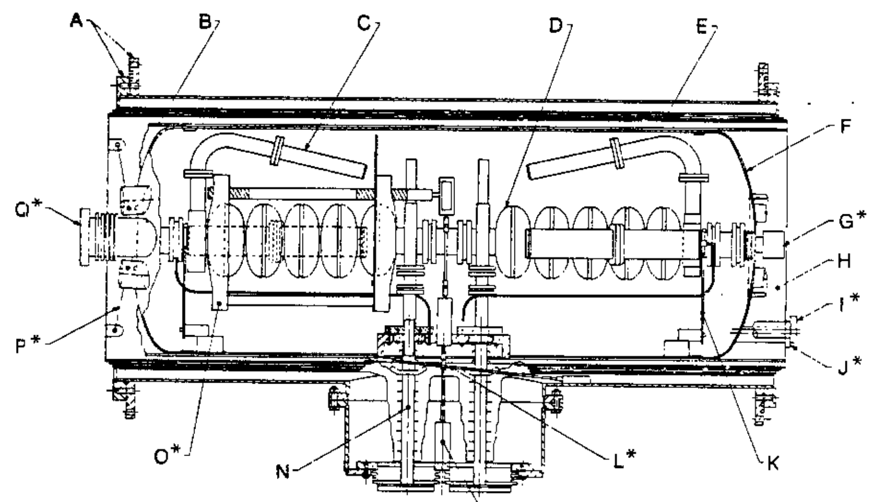
A stepper motor outside the cryostat drives the tuner mechanism through bellows sealed feedthroughs. The tuner is able to resolve the above frequency by compressing the cavity using a differential screw that changes the length of a link attached to yokes on the end cell iris.

Cryounit

Helium Vessel

Each cavity-pair is encased within its own stainless steel helium vessel and other shells to form a cryounit shown in Figure 5. 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. The vessel heads contain the tube penetrations that connect the helium vessel to others in the cryomodule or to the piping in the end cans. A superinsulated pipe, adjacent to the helium vessel, carries the 2.2K supply helium through the cryounit. Using this pipe and the pipe through the shield, the cryomodules act as their own transfer line for those flows. The demountable joint used for all low temperature, stainless steel to stainless steel connections, such as these crossovers, is the Conflat flange.

The input power waveguides, treated in detail in another paper[6] at this conference, are the



A. Vacuum Shell Flange & Captured Seal Ring
B. Magnetic Shield & Inner Superinsulation
C. HOM Load
D. Cavity
E. Shield Superinsulation
F. Helium Vessel
G. Flange Surface on Isolation Valve
H. 40 to 50 K Radiation Shield
I. 2.2 K Helium Supply Line*
J. Shield Connection
K. Outboard Cavity Support
L. Axial Support
M. Rotary Feedthrough
N. Fundamental Power Waveguide
O. Tuning Mechanism
P. Helium Vessel Support Rod
Q. 2 K Helium Return Connection

*Asterisked items shown only once to simplify illustration.

Figure 5 Top View of Cryounit

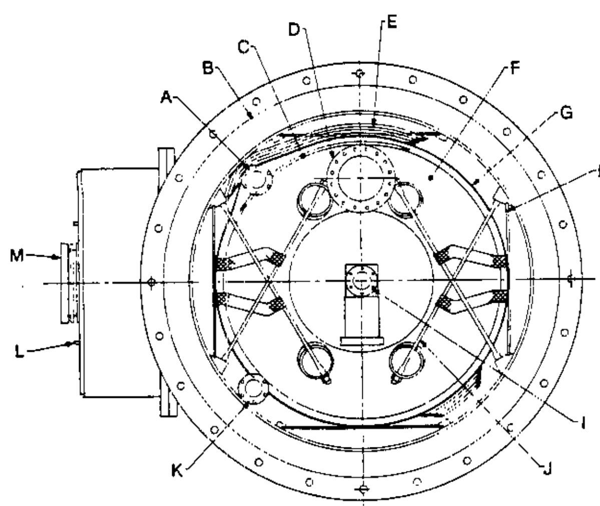
principle penetrations from the exterior into the cryounit helium vessel and represent the greatest heat leak. Conduction to 2 K is minimized by a 55 K heat intercept located 8 cm from the 2 K vessel.

Cryostat

The remainder of the cryounit 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 cryounit as is the helium vessel. It is open ended, to be completed only by bridging to the next cryounit 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.

The vacuum vessel housing the insulation vacuum is made of stainless steel. Flanges at the ends are machined to permit alignment of successive cryounits by simple bolt-up of the O-ring sealed sleeves between cryounits. The cryomodule structural frame is formed by the cryounit vacuum vessels and these sleeves.

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. They are thermally intercepted by connections to the shield. An end view is shown in figure 6.



A. 2.2 K Helium Supply Line
B. Vacuum Shell Flange
C. Magnetic Shield & Inner Supervision
D. 2 K Helium Return Connection
E. Shield Superinsulation
F. Helium Vessel
G. 40 to 50 K Radiation Shield
H. Shield Support
I. Beam Tube Flange Surface on Isolation Valve
J. Helium Vessel Support Rod
K. Shield Connection
L. Rotary Feedthrough Shaft
M. Fundamental Power Waveguide

Figure 6 End View of Cryounit

Cryomodule

Cryounits are assembled into cryomodules. A fill 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 cryounit, and also continues in parallel with the JT valve into the transfer line passing through the first cryounit. The 40-50 K gas input is connected through a thermal shield in the end cap into the shield in the first cryounit. 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 is a closure for the magnetic shielding and closures for the super-insulation blankets.

At the other end of the cryomodule, a return end cap is similarly attached to the cryo-module, 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 cryo-module, 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 chamber, and a guard vacuum antechamber to stop contamination of the sub atmosphere helium. The fitting at the helium gas exhaust contains the module's liquid-level gauge. 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 cryounit. Each stand's feet contain the adjustment mechanisms necessary to position the module on the beam-line axis.

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2. H. Padamsee, D. Mathers, R. Marsh and B. VanDoren, "Advances in Production of High Purity Nb for RF Superconductivity", 1986 Applied Superconductivity Conference, Baltimore, MD.

3. H. Padamsee, et.al., Cornell Internal Report #SRF860502EXA.

4. P. Kneisel, et.al, Cornell Internal Report #SRF860601EXA

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