Review Committee Report

on the

Conceptual Design

of the

Capture Cavity 1 Modifications

Sep 2012

CONTENTS

1. INTRODUCTION

Capture Cavity 1 (CC-1), is a single-cavity cryostat containing one 1.3 GHz 9-cell cavity. CC-1 operated at A0 for many years and will be installed later this year in NML as part of the new Advanced Superconducting Test Accelerator (ASTA) with an updated cavity capable of higher gradient performance (>25MV/m compared to 14 MV/m previously). The old RF cavity will be replaced with a new one that physically differs in several ways: blade tuner rather than end lever tuner (which means a new helium vessel of a different style and different helium piping), reconfigured piping geometry, and a few other modifications. The new design incorporates lessons learned and suggestions made based upon operational experience and the modern design of other single cavity vessels including HTS here at Fermilab.

A review was held in May 2012 to comment on the conceptual design prior to producing detailed fabrication drawings. The review covered the differences between the old CC-1 and the proposed new CC-1. The differences were the result of changes in packaging (including support, tuning and cooling) as well as to improve operating performance of the completed cryomodule based on CC-1 and CC-2 operating experience. This review was a follow-up review to look at the final design solution. Detailed drawings were not reviewed. The final design was presented in a PowerPoint format.

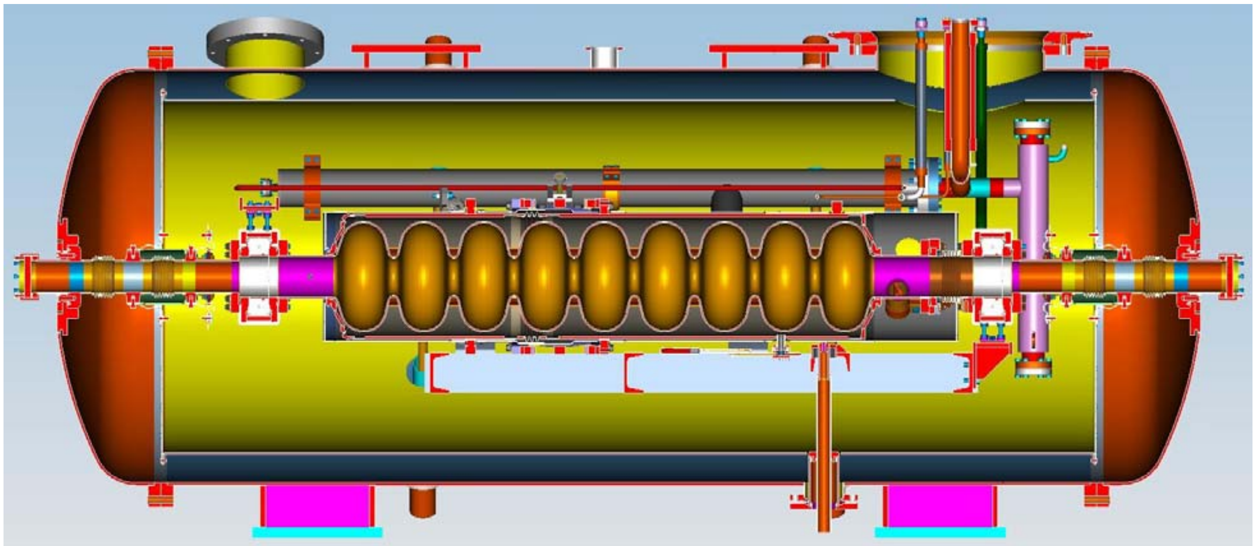

FIGURE 1.1 Capture Cavity 1 Cross Section

2. CONCEPTUAL DESIGN EVALUATION

2.1 Findings from May 2012 Review

Capture Cavity 1 (CC-1) has been successfully operated at the A0 Photoinjector for many years. It is now desired to replace the single 1.3 GHz 9-cell cavity with a higher gradient cavity and install it in the new Advanced Superconducting Test Accelerator (ASTA) at the New Muon Laboratory.

The existing CC-1 used an old cavity design based on the Type 2 cryomodule. This cavity had the two-phase pipe at the 12 o'clock position, utilized the end lever tuner design and had no piezo fast tuners. The helium vessel had unique support brackets that were specific to the mounting method used in CC-1. The new cavity is of the Type 3 cryomodule design which has the two-phase pipe at the 2 o'clock position, utilizes the blade tuner design and has a piezo fast tuner. The cavity mounting brackets are specific to a Type 3 cryomodule and must accommodate cavity tuning motion.

Installation of a new cavity type required changes to the CC-1 cavity support mechanism and internal piping. At the same time, it was desirable to "fix" known problems based on experience with both CC-1 and CC-2 assembly and operation. This includes:

- Removal of the 5 K shield due to space constraints
- Stiffening of the beam tube transition to raise its natural frequency to dampen cavity vibration (based on CC-2 experience and repair)
- Re-orient the beam tube manual valves to be closer to the cavity and horizontal to improve accessibility

Table 2.1 Summary of changes to CC-1

Item	Original	New
Cavity	Type 2	Type 3
Slow Tuner	End lever	Blade
Fast Tuner	None	Piezo
Two-Phase Pipe	12 o'clock	2 o'clock
5 K Thermal Shield	Yes	No
Manual Valves	Between bellows - vertical	Close coupled - horizontal
Support Point	Cavity	Frame

The 5K circuit previously used as the trace tube for the 5K shield will be repurposed as a 5K thermal intercept for items such as the beam tube, power coupler and the support frame.

The use of the blade tuner requires about 1 mm of motion at the non-coupler end. The coupler end of the cavity will be anchored to the support frame. The non-coupler end is shown with a pair of needle bearings allowing axial motion of the cavity and two pairs of needle bearings allowing motion of the manual gate valve.

CC-1 utilized a low thermal conductivity vertical pin to anchor the cavity in the beam direction. This same pin will be used in the new design. It will, however, pin into the support frame instead of the cavity directly.

New manual gate valves will be used. They will be closely coupled to the cavity and mounted horizontally which will conveniently allow them to align with two existing ports in the vacuum vessel. External access to the manual valves in the original design was very difficult.

Many of the thermal intercepts will be of a clamped design (either around a cooling pipe or around the load, in the case of the slow tuner motor or HOM couplers.) Other intercepts, such as the support frame, beam pipe intercepts and connections directly to the 80K shield were generally shown as a single bolted tab on the end of a copper braid.

A new coupler design will be used. The coupler port flange on the cryostat and the radial distance to the cavity are all compatible with the new coupler design.

2.2 Findings from September 2012 Review

Charge question 1: Have the recommendations made at the previous review been addressed satisfactorily?

1. Develop assembly sequence for the end beam tube spools considering cleaning, leak checking, bellows temporary vacuum support and final end cap installation.

   This is being discussed internally and will need to be written down to verify assembly and testing plan.

2. Investigate cumulative tolerance effect on cavity alignment and needle bearing slide performance.

The needle bearing slide sensitivity to tolerance was significantly improved by eliminating the separate upstream gate valve bearing.

3. Investigate pin anchor tolerance and flexing on cavity alignment.

   We were told that an analysis was complete, but we were not shown any results from a tolerance or flexing study of the anchor pin.

4. Investigate alternative cavity and vacuum valve slide scheme in order to minimize the number of bearing surfaces and therefore the potential for binding.

   Complete, see recommendation 2.

5. Add the port to the vacuum vessel and 80K shield to allow access to the slow tuner after understanding the implications on the 80K shield trace tube routing.

   The cost, benefit and schedule impact of implementing the access port resulted in leaving it out of the final design.

6. Analyze the total force on the support rods after considering the increased total weight of the cold mass, pre-stress requirements and cool down stress.

   A steady state thermal analysis was presented considering perfect contact as a means for estimating the heat load to 80K and 2K. No analysis was presented considering the effects of contact resistance on the cryostat performance.

7. Analyze cool down stress and distortion where dissimilar metals are connected or thermal resistance exists.

   This was discussed but not presented.

   Concerning contact resistance, a paper was referenced which used grease as a means for reducing the contact resistance and is planned to be used on the bolted thermal joints.

8. Investigate the thermal effectiveness of the various clamped thermal intercept strap schemes and consider ways to minimize the reliance on small mechanical contact resistance methods.

   There remain many clamped thermal intercepts. Contact resistance is being addressed by adding vacuum grease between the bolted pieces.

9. Develop a preliminary cryomodule assembly scheme in order to ensure that access to components, such as intercept straps or cabling, is convenient.

   An assembly sequence was presented which shows the handling and support of the cavity structure while it is being mounted to the framework. The work needs to be expanded to include the mounting of the piping, insulation, insertion into the vacuum vessel, connection of support rods, connection of all 80K intercept straps, final connection of piping and liquid level can, installation of end bells.

10. Consider if there are practical means for reducing the number of flanged 2K joints within the cryostat.

    The joints have been reduced to a practical minimum for assembling and maintaining the cryostat.

11. With the removal of the 5K shield, the functionality of the 80K shield becomes more important. Carefully consider openings in the shield where 2K surfaces could see room temperature surfaces.

    We were told that it has been integrated into the design. We did not review drawings or discuss insulating techniques for accomplishing this.

12. Add MLI to the helium vessel and two-phase pipe in order to limit the heat load during loss of cryostat vacuum accident.

    This was verified, although the quantity of insulation to be added has not been defined.

13. Evaluate the additional heat load to 2K, both generally and locally at attachment points.

    An analysis was presented showing an estimate of the radiative heat load from 300K to 2K. No other analysis was presented.

Approximately 90 drawings have been prepared.

The current schedule

- Procurement packages complete in early October
  - Requisition process ~1 month
  - Vendor fabrication time ~ 2months
- Assemble at Fermilab ~ 6 weeks

Cryostat complete end of February 2013
Operational readiness review complete March 2013

A P&ID for the cryostat has not been developed.

2.3 Comments

Charge question 2: Is the assembly scheme satisfactory?
The first phase of the assembly has been thought through. The scheme needs to be expanded through the closure of the end bells and include testing points.

Charge question 3: Are drawings, simulations, plans, etc. sufficient to proceed with procurement, fabrication and assembly?
The committee did not review the existing drawing package. The committee feels that there is little risk in proceeding with procurement while the remaining recommendations are addressed.

2.4 Recommendation

1. Develop a method for reliably establishing support rod tensioning using a method such as Belleville washers. This solution will also need to take up thermal contraction of the support rods.

2. Check the modulus of elasticity used for the support rods. A stress of 1.8 MPa seems low for a ½ mm elongation resulting from the static weight.

3. Consider ability to retract support rods , access to the support rod connection points and 80K intercepts with all obstructions in place to ensure proper assembly is possible.

4. Understand the existing operational experience with the equalizing tube to the liquid level measurement. This is particularly important since it may not be practical to regulate to within a portion of the necked down pipe size leading up to the liquid level can.

5. Understand the MLI thickness requirement on the 2K surfaces to adequately limit the relieving requirements.

APPENDIX A

CHARGE TO THE COMMITTEE

The reviewers are asked to objectively review and comment on the overall design as well as specifically address the following:

- Have the recommendations made at the previous review been addressed satisfactorily?
- Is the assembly scheme satisfactory?
- Are drawings, simulations, plans, etc. sufficient to proceed with procurement, fabrication, and assembly?

APPENDIX B

PARTICIPANTS

Review Committee

Mike McGee
Tom Nicol
Rich Schmitt
Jay Theilacker

Presenters

Evgueni Borissov
Nandhini Dhanaraj
Elvin Harmes
Yuriy Orlov
Tom Peterson

Other Participants

Ken Premo

APPENDIX C

REVIEW AGENDA

Wednesday Sep 5, 2012
ICB Headquarters Conference Room

0900:	Introduction/Effort since May Review/Review of Recommendations – Elvin Harms
0915:	Design Considerations – Tom Peterson
0925:	Design & Drawings Overview – Yuriy Orlov
1015:	Finite Element Analysis – Nandhini Dhanaraj
1045:	Assembly Scheme – Evgueni Borissov
1115:	Additional Q&A – All
1145:	Discussion and preliminary conclusions – Committee
1200:	Closeout – All

APPENDIX D

FUNCTIONAL REQUIREMENTS SPECIFICATION

The Functional Requirements Specification did not change between the May 2012 review and the September 2012 review.

FERMILAB
Accelerator Division
SRF Electron Linac Department

Capture Cavity 1 Upgrade
Functional Requirements Specification

Prepared by: Date: Elvin Harms, CC1 Manager	**Organization** AD/SRF Electron Linac Dept.	**Extension** 4387
Reviewed by: Date: Rich Stanek	**Organization** Directorate	**Extension** 3519
Reviewed by: Date: Ken Premo, CC1 Lead Engineer	**Organization** TD/SRF Development	**Extension** 2570
Approved by: Date: Bob Kephart, ILC/SRF Program Director	**Organization** Directorate	**Extension** 3135
Approved by: Date: Mike Church, Head	**Organization** AD/SRF Electron Linac Dept.	**Extension** 2382
Approved by: Date: Jerry Leibfritz, Project Engineer	**Organization** AD/SRF Beam Test Facility	**Extension** 8779
Approved by: Date: Tom Peterson, Head	**Organization** TD/SRF Development	**Extension** 4458
Approved by: Date: Vyacheslav Yakovlev, Head	**Organization** TD/SRF Development	**Extension** 3888
Approved by: Date:	**Organization**	**Extension**

Revision History

Revision	Date	Section No.	Revision Description
1.0	15-Nov-2010	All	Initial Release
1.1	25-Apr-2012	All	After initial review

INTRODUCTION

Capture Cavity 1 (CC1) is a 9-cell superconducting radiofrequency cavity operating at 1.3 GHz which has been in operation in the A0 Photoinjector since 1997. It came from DESY and CEA Saclay and has operated at a peak level of 14 MV/m. In addition to the limit in gradient, inoperability of the slow tuner, presumably due to a shorted motor, has limited CC1 from operating at its optimum, largely due to the inability to adjust its resonant frequency.

With the shutdown of the A0 Photoinjector, CC1 will be repurposed to fulfill a similar role at NML as one of two capture cavities for the photoinjector/electron beam facility (Advanced Superconducting Test Accelerator (ASTA)) currently under construction. As part of its refurbishment, it is intended to remove the cryomodule from A0, replace the existing cavity with one capable of sustaining higher gradients, change the tuner to a blade tuner design, and carry out other upgrades on the support and thermal shield systems. A blade tuner is desired to allow for ‘long pulse’ testing of the SRF cavity in ASTA.

SCOPE OF WORK

The remaining major tasks to prepare CC1 for operation at NML are identified below.

1. Redesign cryomodule internal components to support a cavity outfitted with a blade tuner
2. Identify a suitable cavity, with appropriate gradient and measured performance
3. Assemble cavity and associated internal cryomodule components in vacuum vessel, documenting all steps in the process
4. Test out all systems to the greatest extent possible. These systems include but are not limited to thermometry, RF cable continuity, and tuner operation.
5. Transport CC1 to NML, position and align into its final location in the beamline
6. Make all necessary vacuum, cryogenic, and electrical connections
7. Cool down and bring CC1 into full operation

KEY ASSUMPTIONS, INTERFACES, AND CONSTRAINTS

Little documentation exists on the internal structure of the original CC1 cryomodule. Conversations with the principals assembling it at Fermilab lead to many as yet unanswered questions. Full assessment of the compatibility of the internal plumbing and support structure with another cavity was not possible until the cryomodule was opened. The work moving forward is based upon findings from this internal assessment.

REQUIREMENTS

Operational Requirements

The refurbished CC1 must be capable of sustained operation at a gradient of no less than 25 MV/m. The typical pulse length is 1.3 milliseconds and repetition rate is 5 Hz. These parameters will meet the requirements for CC1 in support of ASTA operation. The cavity's tuner must be of the blade style to facilitate R&D on cavities designed to run with 'long' RF pulses i.e. up to 9 milliseconds.

Technical Requirements

The refurbished cryomodule must interface seamlessly to the existing cryogenics and vacuum systems in NML as well as be compatible with SRF components already installed in ASTA. For uniformity sake – ease of installation and repair, the input coupler, thermometry and other instrumentation/diagnostic signals should be identical to that found in the other SRF devices to the extent possible. In light of advances in design since CC1 was fabricated, modern cryomodule design techniques and sub-assemblies will be pursued while reusing as many of the existing parts as possible.

Specific technical requirements are listed below.

1. Particle-free UHV systems are required to maintain cleanliness and cavity and input coupler volumes at pressures on the order of 10^{-9} Torr.
2. Cryostat must be modified in order to be able to house a 1.3 GHz 9-cell cavity outfitted with a blade tuner
3. In lieu of a 5K thermal shield, provisions will be made for thermal intercepts at 5K.
4. Indirectly cooled components including High Order Mode couplers, tuner motor, and ends beam pipe assemblies shall be thermally anchored to the appropriate cryogenic circuit so as to provide adequate cooling.
5. An adequate support structure, integrated to the existing superstructure, will be designed and fabricated capable of providing the necessary stability for the cavity during transportation and normal operation
6. Cryogenic piping will be positioned and fitted with connections to allow easy interface to the 'top hat'
7. Cernox© resistors will be the thermometry of choice.
8. 80K shield will be modified to allow for relatively easy access to the cavity vacuum isolation valves at each end of the module without compromising the function of the shield
9. Tuner motor will be of a style to provide reliable operation in cryogenic, UHV, and radiation environment.
10. Vacuum vessel flanging will be modified as needed to accept the input coupler attached to the new cavity and accept all instrumentation feeds.
11. All internal components will be supported so as to minimize motion and damp vibration which could adversely affect cavity performance.
12. Alignment checks and fiducials will be provided so as to ensure alignment of the cavity center on the beam line to within 200 microns.

Safety Requirements

The following is a list of safety-related requirements for CC1.

1. Cavity and cryostat must comply with the applicable SRF Cavity and Vacuum Vessel Standards set forth in the FESHM chapters
2. All systems shall be equipped with appropriate relief valves per applicable FESHM chapters to protect against over-pressurization
3. All piping must comply with the ASME/ANSI B31.3 Process Piping design code.

Quality Assurance Requirements

Careful documentation of the disassembly and refurbishment of the CC1 cryomodule, both written and photographic should be kept. This allows for ease in troubleshooting should problems arise during operation. A complete set of 'as found' drawings will be prepared once the work is finished. To the extent possible, the tuner, instrumentation, and electrical connections will be tested and confirmed operational prior to closing up the vacuum vessel.

Test/Commissioning Requirements

The 1.3 GHz 9-cell cavity to be installed in CC1 has been previously tested at Fermilab and the results documented. During installation in ASTA all vacuum and cryogenic circuits will be leak checked to the most sensitive scale reasonably achievable, nominally 10^{-9} atm.-cc/sec.

Commissioning of CC1 will occur in its final location in the ASTA tunnel at NML following nearly identical protocols as was done for CC2. This commissioning includes warm low power operation to condition the input coupler as well as on-resonance coupler conditioning and a full suite of performance tests.

REFERENCES