REBUILD OF CAPTURE CAVITY 1 AT FERMILAB*

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Abstract

The front end of the proposed Advanced Superconducting Test Accelerator at Fermilab employs two single cavity cryomodules, known as 'Capture Cavity 1' and 'Capture Cavity 2', for the first stage of acceleration. Capture Cavity 1 was previously used as the accelerating structure for the A0 Photoinjector to a peak energy of ~14 MeV. In its new location a gradient of ~25 MV/m is required. This has necessitated a major rebuild of the cryomodule including replacement of the cavity with a higher gradient one. Retrofitting the cavity and making upgrades to the module required significant re-design. The design choices and their rationale, summary of the rebuild, and early test results are presented.

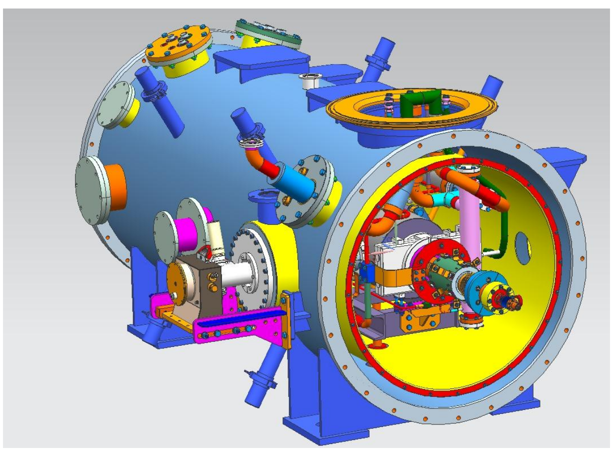

Figure 1: CC-1 Upgrade.

INTRODUCTION

Capture Cavity 1 (CC-1, Fig. 1) was the primary accelerating component of Fermilab's A0 Photoinjector for many years. In late 2011 the Photoinjector was tuned off and decommissioning begun. The advanced accelerator R&D work carried out there is expected to continue at Fermilab's Advanced Superconducting Test Accelerator (ASTA). CC-1 will serve as the first of two booster cavities immediately following the Photoinjector gun. Figure 2 shows the layout of the 50 MeV section of ASTA.

Construction of ASTA is well underway with the electron gun, CC-2, and accelerating cryomodule installed and commissioning begun. Exclusive of beam line and magnets, CC-1 is the final major component yet to be put into place.

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While it provided many years of reliable service at A0, CC-1 had operational drawbacks that were deemed necessary to correct or improve prior to being put into use in its new location. Primary were a peak gradient limitation of 14 MV/m and inability to adjust its resonant frequency due to a non-functioning tuner motor. In addition it was determined that future R&D at ASTA could be enhanced if the cavity were to be able to be tuned via a blade tuner with 'fast' piezo actuators rather than the existing end lever style tuner.

UPGRADE CONSIDERATIONS

Since the CC-1 design dates to the mid 1990's and fifteen years have passed since CC-1 was first brought into operation at Fermilab it was determined that in addition to replacing the cavity itself with a better performing one, updates in technology and applying operational lessons learned would be part of the upgrade.

Functional Requirements

Requirements were laid out for the upgrade including:

- The refurbished cryomodule must interface seamlessly to the existing cryogenics and vacuum systems 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 CC-1 was fabricated, modern cryomodule design techniques and sub-assemblies will be pursued while reusing as many of the existing parts as possible.

Original Design of CC-1

After delivery to Fermilab from DESY, CC-1 began operation in late 1998. It was originally built in France and placed into operation at DESY prior to its service at Fermilab. Its features are described previously [1]. The radial suspension system utilizing split suspension rings and epoxy-fiberglass radial supports has proven to be a well-designed, efficient alternative for single-cavity cryomodules assuring minimal heat loss and good mechanical stability. CC-1 as built is a legacy "Type 2" cryomodule cross-section with the 2-phase pipe directly above the cavity. Tuning was accomplished by an end lever tuner with no piezo (fine or fast) tuner mechanism. The cavity was encased in both an 80 Kelvin (K) and made to fit 5 K thermal shields. Internal gate valves were oriented vertically making access to them difficult.

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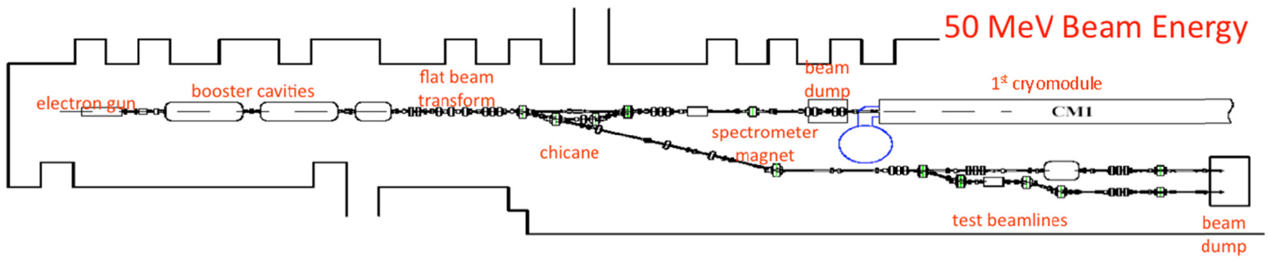

Figure 2: Proposed ASTA layout for up to 50 MeV. Capture Cavity 1 is the first (leftmost) of the two booster cavities immediately downstream of the electron gun.

New CC-1 Features

The upgraded module contains a dressed TTC-style cavity identical to those in ASTA's main accelerating cryomodule, CM-2. The 2-phase pipe position is off-center as in a "Type 3" helium vessel. The helium piping has been reworked to match this orientation. In lieu of a dedicated 5 K shield, thermal intercepts from the support frame to which a 5 K trace line is anchored are provided instead. The internal gate valves have been re-oriented in the horizontal position and ports through the 80 K shield have been opened to make them more accessible. These ports line up with existing flanges in the outer vacuum vessel. Care was taken to not compromise the shield's effectiveness nor introduce heat leaks (Fig. 3).

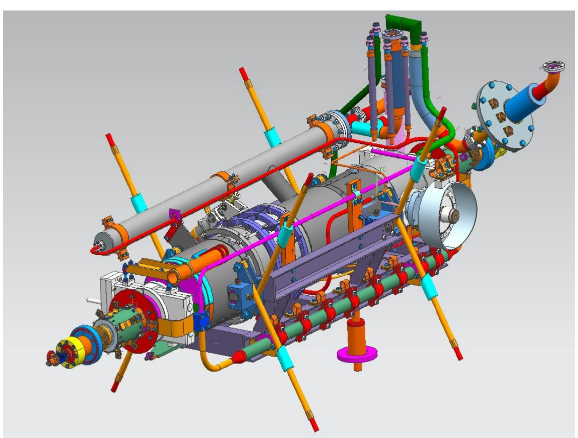

Figure 3: Design of CC-1's internals showing the dressed cavity, input coupler, upstream end bellows and valve assembly, cryogenic and relief piping, tension support rods, and support frame. The axial support is visible at the bottom.

Incorporating a cavity outfitted with a blade tuner required designing a hybrid support scheme that would compensate for the accompanying slight motion of the helium vessel. The tension rod supports were retained, but now are tied to the needle bearing housings which are typically found supporting Tesla-style cavities. Additionally the internal vacuum valves are attached more closely to the cavity ends than before, requiring support of them also to be integrated to the cavity support structure. Finite Element Analysis was performed and verified that the rods could adequately handle the increased weight of the cavity, support frame, and gate valves. The axial support finger device is also retained to maintain the cavity's longitudinal position in the vacuum vessel.

Not just the cavity was replaced, but the input coupler, also a TTF-type, needed to be integrated into the final cryomodule design. Fortunately the legacy coupler was fundamentally identical, dimensionally, to the existing one.

Tooling and procedures to ensure insertion of the cavity into the vessel and attachment of end groups without compromising the pristine state of the cavity also required special care. Fit-ups and mock assemblies were beneficial in assuring success.

Application of Past Experience

Several lessons learned over the years of cryomodule design and operation, including experience with CC-1 itself and especially the Horizontal Test Stand at Fermilab factored into other design considerations. The end bellows are better supported to prevent vibration and thermal intercepts are incorporated. Vibration of the ends initially affected operation of CC-2 initially prompted modifications to it [2]. These changes were integrated into the re-design of the ends here. Thermal isolation between the support frame and cavities in the Horizontal Test Stand leading to long delays in reaching thermal equilibrium led to a study and final design for an aluminum frame structure with effective thermal intercepts.

Recent R&D on Blade tuner operational robustness led to incorporating the latest improvements including a drilled motor shaft and Loctite™ sealing.

CC-1 was originally outfitted with 'internal sight lines', optical windows through which targets on the cavity could be viewed externally. This scheme has been replaced in favor of an AC Wheatstone bridge circuit between mounts on the cavity and inner surface of the vacuum vessel. Bench tests suggest a resolution of order microns. Although beam-based alignment schemes will determine cavity movements with respect to the beam line, this diagnostic may prove beneficial to monitor cavity movement during cool down.

Taken in sum these changes are expected to make CC-1 a stable cryomodule in virtually all operational aspects.

NEW CAVITY

The cavity selected for placement in CC-1 is identified in Fermilab nomenclature as TB9RI029 or simply RI-029 (Fig. 4). It was given bulk electro-polishing by the manufacturer prior to shipment to Fermilab. Following both 800 °C and 120 °C bakes it achieved a peak gradient of 34.6 MV/m during vertical testing. Performance was limited by quench with no field emission detected. Its final test at Fermilab's Horizontal Test Stand as a dressed cavity resulted in a peak gradient of order 29 MV/m, consistent with a previous test done at HTS nearly three years earlier. Between tests the cold end of the coupler was replaced hoping to bring the peak gradient closer to the vertical test result. Quenching limited the peak gradient. Dynamic heat load measurements resulted in:

$$Q_0 = 1.1 \pm 0.3 \times 10^{10} \text{ at } 26 \text{ MV/m and}$$

$$Q_0 = 0.78 \pm 0.13 \times 10^{10} \text{ at } 28 \text{ MV/m.}$$

The final horizontal test also served as a helpful data point that cavity performance is retained for years if a cavity is stored under proper conditions.

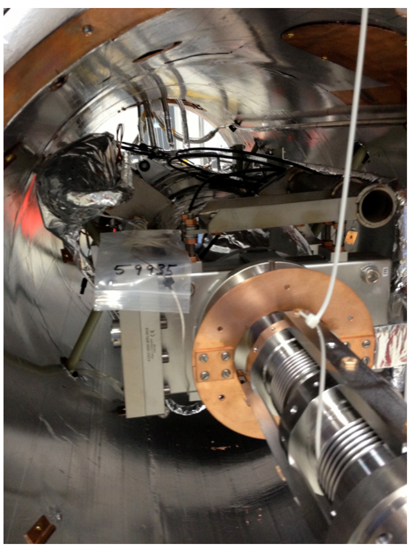

Figure 4: CC-1 internal view with new cavity inserted.

UPGRADE STATUS

As of this writing mechanical work on CC-1 is largely complete. The cavity has been installed into the vacuum vessel, most piping installed and leak checked, and initial alignment completed. Necessary pressure tests have been successfully carried out as well. Relief venting, following the scheme used for CC-2 and the accelerating cryomodules at ASTA, requires some additional internal piping rework. In its previous incarnation at A0, the helium circuit for CC-1 had its relief venting through the cryogenic feed 'top hat'. The typical scheme now is to directly relieve the circuit at the 2-phase line using a dedicated line through the cryomodule. Design is completed and procurement is in progress (Fig. 5). This work is expected to be complete soon. Following this final assembly including alignment of the cavity and instrumentation installation and checkout will follow. To the extent possible, all thermal sensors, tuner motor, etc. are verified functional prior to final close-up.

SUMMARY

Although the individual upgrades for CC-1 individually employ proven techniques or designs, the overall effort, has proven to be a more ambitious exercise than originally envisioned. In part this was due to not knowing what exactly would be found once the module was opened and disassembly begun. Unexpected occurrences, such as leaks of the braze joints on the 80 K shield introduced unplanned delay. This project has proven to be a useful exercise that called upon quite a variety of design and assembly skills.

Two reviews were conducted of the program – when the original design work was completed and once more immediately prior to procurement and fabrication. Both exercises were helpful in identifying potential design snags, means to simplify assembly, not to mention verification of design paths [3].

ACKNOWLEDGEMENTS

The work and attention to detail by the SRF Cryomodule Fabrication group, as well as the design and drafting team in Fermilab's Technical Division have brought this effort nearly to completion. We recognize the fine initial design of the Capture Cavity cryostat (Cryocap) by colleagues from Orsay.

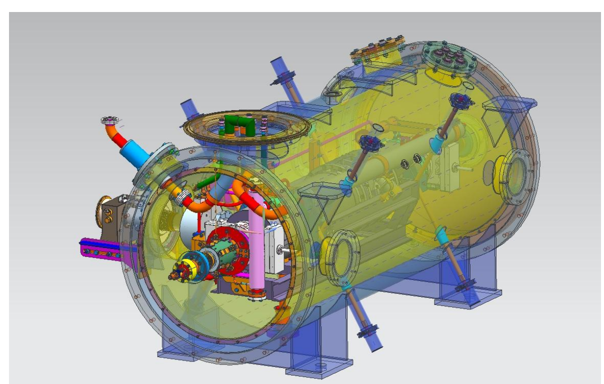

Figure 5: Cutaway view of completed CC-1 Upgrade (end domes removed).

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