CRYOMODULE DESIGNS FOR SUPERCONDUCTING HALF-WAVE RESONATORS*

Z.A. Conway#, G.L. Cherry, R.L. Fischer, S.M. Gerbick, M.J. Kedzie, M.P. Kelly, S.H. Kim, J.W. Morgan, P.N. Ostroumov and K.W. Shepard, ANL, Argonne, IL 60439, USA

Abstract

In this paper we present advanced techniques for the construction of half-wave resonator cryomodules. Recent advances in superconducting low-beta cavity design and processing have yielded dramatically improved cavity performance which reduces accelerator cost and improves operational reliability. This improvement has led to the proposal and construction of half-wave resonators by ANL for the acceleration of $0.1 < \beta < 0.5$ ions, e.g., the SARAF Phase-II project at SNRC (SOREQ, Israel) and Project-X at Fermilab. These cryomodules build and improve upon designs and techniques recently implemented in upgrades to ATLAS at ANL. Design issues include the ease of assembly/maintenance, resonator cleanliness, operating at 2 or 4 Kelvin, and ancillary system interfacing.

INTRODUCTION

We are developing three separate cryomodules for two distinct projects: one for Project-X at FNAL [1] and two for SARAF Phase-II at SOREQ [2]. The cryomodules for these projects will house superconducting half-wave resonators [3, 4] which require similar layouts but differ in operation modes and dimensions. To reduce risk and optimize the cost of the cryomodule fabrication we are developing the three designs together. All designs are modifications and improvements on box-cryomodules fabricated at ANL in the past 5 years [5, 6].

In this paper several aspects of the designs and their differences will be presented. First, the cryomodule requirements will be discussed. This is followed by a discussion of a few select aspects of the cryomodule designs, differences and plans for addressing these differences. Finally, this paper concludes with a short statement of our future plans.

CRYOMODULE REQUIREMENTS

Project-X is a high intensity, 1 mA, H^- linear accelerator facility being developed at FNAL. A single half-wave resonator cryomodule will house 8 $\beta = 0.11$ 162.5 MHz superconducting cavities, 8 superconducting magnets and will operate at 2 K.

The SARAF Phase-II project is an upgrade of the current SARAF accelerator to accelerate >5 mA, 40 MeV/u, proton/deuteron beams. Four cryomodules are required of two types, all of which will operate at 4 K. The first type, the low-beta cryomodule, contains 7 $\beta = 0.09$ 176 MHz superconducting cavities and 7 superconducting magnets. The second type, two high-beta cryomodules, each housing 7 $\beta = 0.16$ 176 MHz superconducting cavities and 4 superconducting magnets [7].

While the accelerator lattice and operating temperature differ between the cryomodules enough similarities exist such that we see significant cost savings in designing a cryomodule which may be adapted to each case, with minor modifications.

CRYOMODULE DESIGN

Vacuum Vessel

The cryomodule designs all build upon past ANL experience with box-cryomodules (see for example [5]). Here the cryomodules are much wider due to the half-wave cavities being mounted on their sides. To keep the half-cylinder bottom would make the vacuum vessels unacceptably tall. We have arrived at making the vacuum vessel a box which appears to be a good compromise between fabrication cost, structural integrity and minimizing cryostat height. The radii of the rounded corners were chosen to fit the contents of the box minimizing overall height including the depth of the required gussets.

Figure 1 shows the results from ANSYS calculations of the structural deformations due to vacuum being pulled on the inside. Notice that the structure pulls in about 0.25” on average due to evacuation, the maxima are between 0.5” and 0.67”. We are currently evaluating whether or not to stay with this or reinforce the box further. Motion of the vacuum vessel wall moves the internal magnetic shielding and stresses the baton points which may degrade performance. Reducing the maximum displacement to less than 0.25” will avoid this but it adds the cost of additional gusseting. Future tests are planned here to evaluate the magnetic shielding.

With the rounded corners the vacuum vessel dimensions may be scaled between the three different sizes required by varying the length of the straight sections. Other designs we considered included straight sides (too mechanically compliant), angled corners (more expensive to fabricate), and a half-cylinder bottom (makes the cryomodule too tall). All of these designs were discarded for the mentioned reasons.

Beam-Line Component Support and Alignment

While the required accelerator lattice varies between the cryomodules the same support scheme may be used. All of the cryomodules require the solenoids to be aligned to better than ± 1.0 mm_{peak} transversely with $\pm 0.1^0$ for all of the rotation angles with similar constraints on the cavities. The beam-line string length varies from 4 to 6

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zconway@anl.gov

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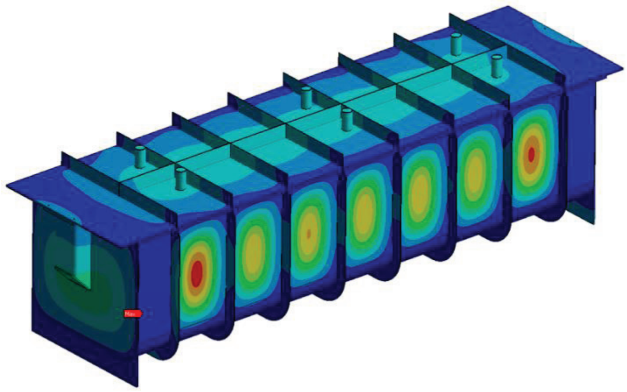

Figure 1: ANSYS results of the vacuum vessel deformation due to a 14.7 psi static pressure gradient across the walls. The red color corresponds to displacements greater than 0.6 inches with the maximum being 0.67 inches.

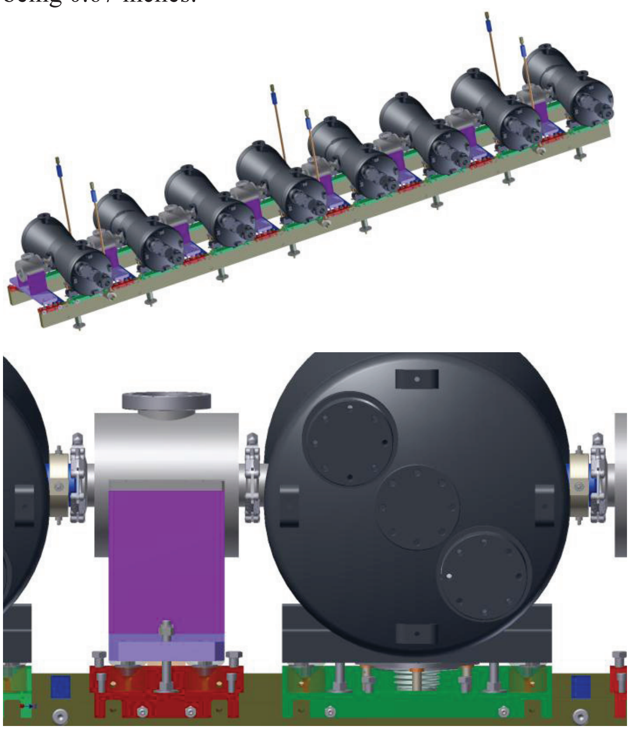

Figure 2: (Top) A cavity/solenoid string mounted on a strong-back. (Bottom) A close up of the alignment hardware for a solenoid and a cavity. The runners move transversely by adjusting two screws which push and two screws which pull (screws not shown but threaded holes they mate with are). One of each adjustment type is on each corner. The runners can be moved up and down by adjusting two vertical screws and placing shims between it and the strong-back.

meters and will be supported and aligned on a cryomodule spanning titanium rail system, called the strong-back. The strong-back is composed of 2 inch x 8 inch grade 2 titanium plates formed into a box and supported by titanium hangers. Each component is mounted on top of the strong back with its own independent kinematic-alignment hardware. Figure 2 shows the strong-back assembly for a cryomodule string.

Notice the green and red (colors chosen for contrast) runners each of the cavities and solenoids sit on. These runners are adjustable on the strong-back for final fine-alignment. Recent experience with a 7 cavity and 4 solenoid cryomodule demonstrated that using this technique all of the components over a 4.5 meter length can be aligned to better than ±0.25 mm_{peak} transversely with $\pm 0.15^0$ for all of the rotation angles, exceeding our current transvers requirements by a factor of 4. The angular alignment was only limited by the travel in our alignment system and our future hardware will have an additional 0.125 inches of motion.

Our favourable result at room temperature will be verified at 4 K in the next several months. To address this in our developing designs we have studies the behaviour of the strong-back due to loading and cool-down. Figure 3 shows the loading of the strong-back. We have optimized the position of the hangers to minimize distortion due to the weight of the components and their ancillary equipment. The hanger positions may be very closely calculated by hand. One must only balance the torque about each support to get a hanger distribution which varies from the ANSYS optimum by 1 cm over the 6 meter length of the model shown. Figure 4 shows the change in the strong-back shape due to thermal contraction. The loading elements are part of this simulation; they are suppressed in this figure to show more of the strong-back. The side-views are shown in figures 3 and 4 since there is negligible twisting of the strong-back.

In all of the simulations no component is perturbed by more than 0.1 mm_{peak} and 0.0005^0 well within our alignment tolerances. If tests with current hardware confirm similar simulations we will be able to align the entire beam-line assembly at room temperature without having to adjust for differential displacements of components due to cool-down.

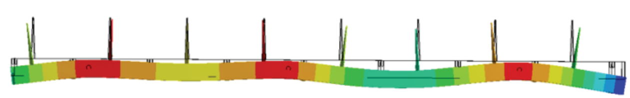

Figure 3: Side view of the strong-back showing the displacement due to the weight of the beam-line components. The maximum displacement is 0.13 mm, dark blue. The outlined shape is the undeformed model.

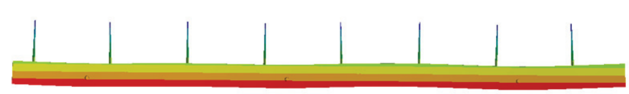

Figure 4: Side view of the strong-back showing the displacement due to thermal contraction and component loading. The maximum displacement is 0.05 mm. The outlined shape is the undeformed model. Notice the displacements decrease as the titanium elasticity decreases due to cool-down.

These results demonstrate that the beam-line components can all be aligned on a single long (> 4 m) strong-back. Short independently alignable cryomodules housing one or two components are not required. This saves significant cost in fabricating one large vacuum vessel instead of several shorter ones.

Cryomodule Cryogenics

A major difference between all of the cryomodules we are currently developing is the operating temperature. To accommodate this we are designing almost identical 2-4 K helium distribution systems. The 2 K option has a sub-cooled heat exchanger and a J-T valve. These components are removed from the design and replaced with direct bayonet connections to the helium distribution system for the 4 K option.

Several smaller differences of operating at 4 instead of 2 K:

- Shorter beam-line gate valves, remove one of the thermal transition sections. Figure 5 shows a cross-section of the 2 K beam-line gate valve model.
- Eliminates the need for conduction cooled superconducting magnet leads.
- Eases the leak checking of the cryomodule since superleaks are no longer an issue.
- All of the 5 K intercepts are either eliminated or not connected.
- Radiative warming of the 4 K helium system by the slow tuners is neglected, resulting in an increase in the thermal load of 0.5 W. This load is reduced in the 2 K design using multi-layer insulation and larger washer stacks to thermally isolate the slow tuners.

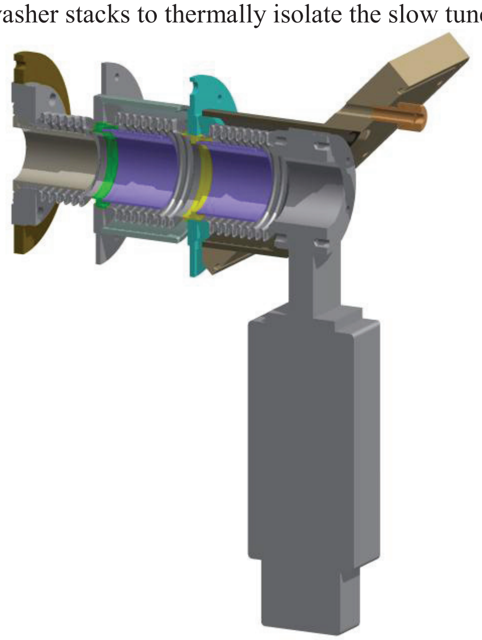

Figure 5: Cross section view of the beam-line gate valve. The total heat leak to 2 K in this design is < 0.05 W. For the 4 K cryomodules the final bellows segment on the left will be removed.

FUTURE PLANS

Our plans are two fold; (1) continue the modelling and (2) benchmark the modelling with physical measurements. The future modelling will be focused on reducing the number of vacuum vessel gussets (to minimize fabrication cost at $5k apiece), evaluating the structural integrity of the final design to ensure compliance with all US and DOE safety requirements, and to refine our understanding of the beam-line string alignment. In the next 6 months we will be able to measure and quantify the motion of a 4.5 meter long titanium strong-back which will provide useful insight into the simulations. We hope to begin fabrication of the first of these three cryomodules in the next two years.

ACKNOWLEDGMENTS

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