A NEW HALF-WAVE RESONATOR CRYOMODULE DESIGN FOR PROJECT-X*

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Abstract

We present the current status of our Project-X half-wave resonator cryomodule development effort. The Project-X injector requires a single cryomodule with 8 superconducting 162.5 MHz β = 0.112 half-wave resonators interleaved with 8 integrated superconducting solenoid/steering coils. This cryomodule is being designed and built by ANL with the intent of delivering a device which has all external connections to the cryogenic, RF, and instrumentation systems located at removable junctions separated from the clean cavity vacuum system. Issues include the ease of assembly, cavity cleanliness, interfacing to subsystems (e.g., cryogenics, couplers, tuners, etc), and satisfying the ANL/FNAL/DOE guidelines for vacuum vessels. We employ proven warm-to-cold low-particulate beam line transitions to minimize unused space along the linac, a top loading box design that minimizes the size of the cleanroom assembly, and compact beam-line devices to minimize the length of the focusing period.

INTRODUCTION

Project-X is a high intensity H^- linear accelerator facility being developed at FNAL to support an advanced U.S. program in Intensity Frontier physics over the next several decades [1]. The Project-X Injector Experiment (PXIE), is being designed, built and commissioned as a demonstration of the most critical R&D issues related to the front-end of the driver linac [2].

The PXIE project will include the beam source, LEBT, RFQ, MEBT, and two superconducting cavity cryomodules. The first superconducting cavity cryomodule will house 8 half-wave resonators, 8 magnets which integrate the focusing solenoids with x-y steering coils [3], and all of the necessary peripherals for operation, e.g., power couplers, slow tuners, etc.

In this paper we report on the status of the cryomodule design development. Here we address the cavity subsystems and the cryomodule design. The status of the superconducting half-wave resonator work is addressed in [4].

HALF-WAVE RESONATOR SUBSYSTEMS

Several subsystems must be integrated not only with each resonator but also with the overall beam-line string. These systems include the power couplers, slow mechanical tuners, vacuum systems, support and alignment systems, superconducting magnets (focusing and steering), cryogenic distribution, and beam-position monitors.

The power couplers are being designed for 10 kW forward RF power and capable of operating under all reflection conditions, e.g., operating anywhere from the extreme weak to the strong coupling regimes. The coupler design is an improvement upon a previous design for 4 kW operation. The coupler design methodology has been benchmarked with the 4 kW coupler and thermometric measurements of the coupler agree within the experimental error [5].

The pneumatic slow tuners are improved versions of the previous design used successfully for the past 4 years in the ATLAS Energy Upgrade Cryomodule [6]. Figure 1 shows the tuner mounted on a cavity.

The beam-line vacuum system is evacuated via a manifold connected to each cavity with a dedicated pump-out line which is assembled and hermetically sealed during the clean assembly, minimizing the risk of particulate contamination to the superconducting cavities. The system is designed for low-particulate operation and will be manufactured from 300 series stainless steel, electropolished, high-pressure water rinsed with ultra-high purity water (R >17 MΩ-cm), and then installed on the cavity string. The system will provide a minimum pumping speed of 75 l/s at each of the 8 cavities which enables high-vacuum (< 1 e-7 torr) operation at room temperature.

The focusing period in this cryomodule has been minimized by following a novel approach to the solenoid, beam-position-monitor (BPM), and interconnecting spools. Instead of using the traditional Con-Flat® type flanges EVAC CeFix [7] flanges may be used. These flanges eliminate all the threaded fasteners in a low-particulate region which must be kept clean to minimize field emission in the cavities, a significant improvement over the Con-Flat® flanges. The superconducting magnets are being developed in collaboration with Cryomagnetics, Inc. and Meyer Tool and Manufacturing, Inc. The magnet design integrates the x-y steering coils with the focusing solenoid to save length. Finally, a compact BPM is being prototyped and will be tested with beam at ATLAS this fall, see figure 3.

The cavity/magnet support and alignment system provides a rigid platform for each cavity and magnet and allows for the independent alignment of each element. This system is structurally supported by a titanium I-beam rail system which runs the length of the cryomodule and supports all of the beam-line elements. The cryomodule

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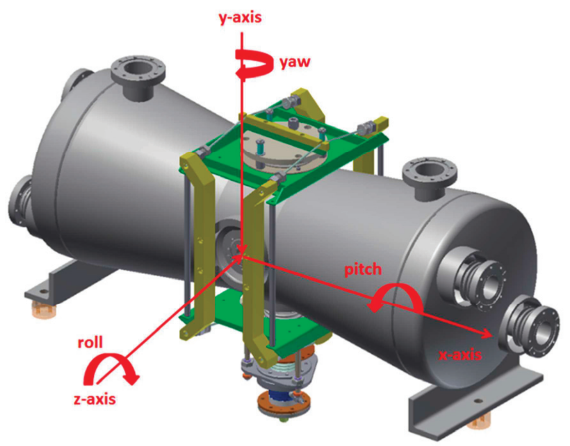

Figure 1: (Top) The cavity alignment coordinate system and slow tuner. Notice the small circular pucks on the bottom of the cavity (two visible) these are the kinematic supports. (Bottom) Slow tuner assembly. The slow tuner bellows actuator is on the left and the outward force on the wire ropes is translated into a reduction of the beam-line length of the cavity by the bars that attached to the beam port in the middle and the wire ropes on their ends.

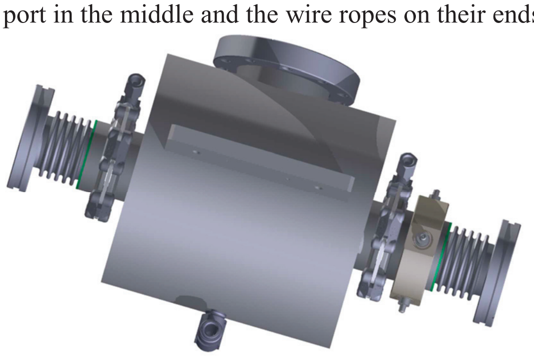

Figure 2: The superconducting magnet with EVAC CeFiX flanges, formed metal bellows which connect to the half-wave resonators and the beam-position-monitor. The magnet integrates an 6 T superconducting solenoid with x-y steering coils. As shown the length is 40 cm.

spanning strong-back alignment technique has been in use at ATLAS for the past 25 years and was recently measured to hold the alignment of elements to better than 250µm and 0.1^0 typically [8]. Each individual element will be supported by a Maxwell-type kinematic mounting arrangement [9] and the alignment targets for the elements, along with recently achieved results are shown in Table 1. Here notice that we are in the process of assembling a new cryomodule for the ATLAS Intensity Upgrade which will serve as a proving ground for the technology to be used in the PXIE half-wave resonator (HWR) cryomodule. The Maxwell kinematic support structure was chosen because the beam axis of the cavity does not displace along the x-axis (Figure 1) during cooldown. This arrangement is shown in Figure 1. Each cavity and magnet will have 4 targets, mounted on fiducial surfaces referenced to the electrical axis of the devices, which will be used for alignment with the beam

Table 1: Alignment Results and Specifications, the Energy Upgrade column is from measurements with beam while the other two columns are the alignment targets. Refer to Figure 1 for the coordinate system definition.

Dimension	2009 ATLAS Upgrade	2013 Intensity Upgrade	PXIE HWR Cryomodule
x(mm)	±0.25	±0.25	±0.25
y(mm)	±0.25	±0.25	±0.25
z(mm)	±1	±1	±0.50
Pitch	$\pm 0.1^0$	$\pm 0.1^0$	$\pm 0.06^0$
Yaw	$\pm 0.1^0$	$\pm 0.1^0$	$\pm 0.06^0$
Roll	$\pm 0.5^0$	$\pm 0.1^0$	$\pm 0.06^0$

axis and optical monitoring for misalignment measurements during all stages of the cryomodule life-cycle: assembly, pump-down, cool-down, operation, warm-up etc.

CRYOMODULE

The PXIE HWR cryomodule design is an evolution of the top-loaded box cryomodule design used successfully for the ATLAS Energy Upgrade Cryomodule [6]. Several improvements have been made as well as modifications for 2 K operation. We are working on an optimized vacuum vessel design to minimize the cost of fabrication, reduce the space required in the accelerator hall, and satisfy the pressure vessel safety guideline set forth by FNAL. The cryomodule vessel design has only just begun and is expected to be complete in the next 4 months.

The PXIE HWR cryomodule layout was determined with careful beam-dynamics simulations and estimates of recent cavity performance [2,10]. This work determined that a focusing period contain a magnet-BPM-cavity sequence and that 8 of these units were required. The cryomodule design is developed around these requirements. The cryomodule beam-line assembly along with the strong-back, cavity subsystems, and strong-back hangers is shown in Figure 4.

The main difference between this cryomodule and our previous designs is the operating temperature, 2 K. To account for this we are incorporating thermal shielding at 70 K, intermediate thermal intercepts at 5 and 70 K, and a cryogenic distribution system compatible with the supplies supplied in the accelerator hall. The helium distribution system does not supply gas but rather supercritical 5 K helium gas. Internal to the cryomodule the 5 K supply is split to supply the 5 K thermal intercepts and a heat exchanger followed by a J-T throttle valve to supply the 2 K liquid for the cavity and magnetic cooling. The heat exchanger and J-T valve combination are based upon a similar configuration used for the past 3 years in our test cryostat. The heat exchanger is based upon the models developed for the LHC cryogenic distribution

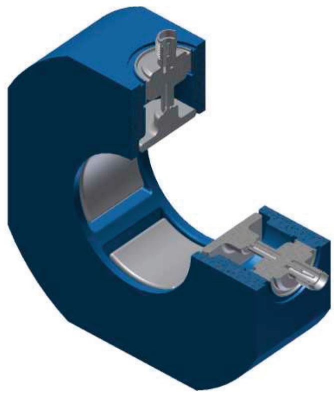

Figure 3: A quarter-section view of the BPM. As shown the BPM is 1" long with a maximum diameter of 3.7" and a beam aperture of 33 mm, the PXIE requirement.

system and described in [11]. In the PXIE HWR cryomodule the design throughput is 5 g/s. A recent FNAL recommendation to increase this to 7 g/s is being pursued and requires the installation of a larger heat exchanger, for which sufficient space is available. The cryomodule is designed for clean assembly of the cavities, couplers, magnets, interconnecting beam-spools, beam-line gate valves, and vacuum manifold. All of these parts have been designed to be cleanable via ultrasonic cleaning and high-pressure ultra-high purity water rinsing. The cryomodule design for the clean assembly builds upon our previous work and minimizes the number of components and connections which must be handled/made in the cleanroom.

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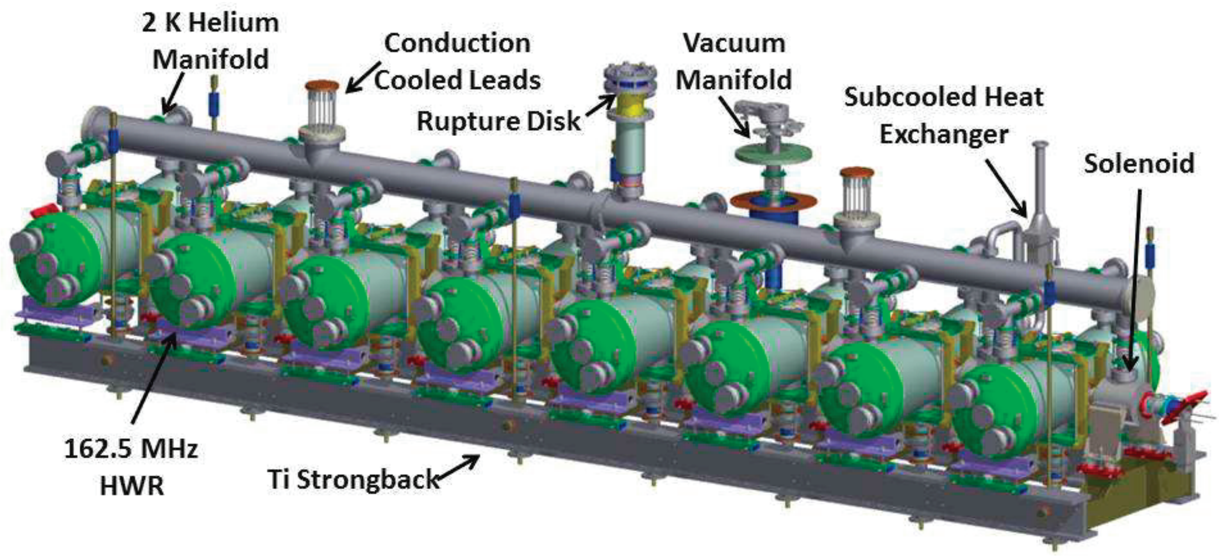

Figure 4: The cryomodule beam-line assembly. The clean cavity vacuum manifold is behind the assembly but the lid penetration is visible behind the helium manifold. The assembly as shown is 5.9 meters long. The cryomodule still remains to be designed but initial estimates give a width and a height of 1.7 m and 2.0 m respectively.