

PROGRESS IN CAVITY AND CRYOMODULE DESIGN FOR THE PROJECT X LINAC*

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Abstract

The continuous wave 3 GeV Project X Linac requires the development of two families of cavities and cryomodules at 325 and 650 MHz. The baseline design calls for three types of superconducting single-spoke resonators at 325 MHz having betas of 0.11, 0.22, and 0.42 and two types of superconducting five-cell elliptical cavities having betas of 0.61 and 0.9. These cavities shall accelerate a 1 mA H- beam initially and must support eventual operation at 4 mA. The electromagnetic and mechanical designs of the cavities are in progress and acquisition of prototypes is planned. The heat load to the cryogenic system is up to 25 W per cavity in the 650 MHz section, thus segmentation of the cryogenic system is a major issue in the cryomodule design. Designs for the two families of cryomodules are underway.

INTRODUCTION

The Project X linear accelerator (linac) is being designed to provide a continuous-wave 3 GeV 1 mA H-beam to an experimental area and a pulsed 8 GeV 1 mA proton beam for injection into the Main Injector. These beams will support a variety of experiments in kaon, muon, nuclear, and neutrino physics [1-3]. The linac will utilize superconducting 325 MHz single-spoke cavities, 650 MHz elliptical cavities, and 1300 MHz Tesla-type cavities in ILC-like cryomodules. Six distinct cavity designs are planned spanning the velocity range from $\beta=0.11$ to $\beta=1$. These cavities will be assembled into three different types of cryomodules. All cavities will operate at a temperature between 1.8 and 2.1 K.

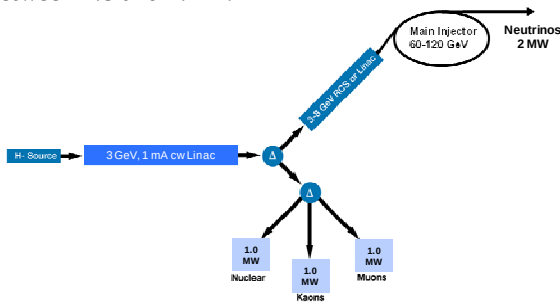


Figure 1: Schematic layout of the accelerator complex.

The designs of the cavities and cryomodules are in progress. Prototype $\beta=0.22$ single-spoke cavities have already been produced and tested with encouraging results. Prototype single-cell 650 MHz cavities are in production, and it is planned to initiate procurements of

prototype $\beta=0.11$ single-spoke cavities this year. The cryomodule designs are in the conceptual design stage. Segmentation of the linac, which determines the number of cavities per cryomodule, is based on lattice requirements, heat load, and reliability issues. Development of auxiliary components such as RF power couplers, cavity tuning systems, higher-order-mode (HOM) couplers, and helium vessels is underway.

The basic layout of the Project X accelerator complex is shown in Figure 1. The main parameters of the different linac sections are listed in Table 1.

The 3-8 GeV pulsed linac will utilize 1300 MHz Tesla-type cavities in ILC-like cryomodules. The remainder of this document will focus on the development of the cavities and cryomodules for the continuous-wave 3 GeV linac.

Table 1: Parameters of the linac sections.

Section	Freq (MHz)	Energy (MeV)	No. of C/FE/CM	Component Type
SSR0 $\beta=0.11$	325	2.5-11.4	18/18/1	single-spoke cavity, solenoid
SSR1 $\beta=0.22$	325	11.4-43	20/20/2	single-spoke cavity, solenoid
SSR2 $\beta=0.4$	325	43-179	44/24/4	single-spoke cavity, solenoid
LB 650 $\beta=0.61$	650	179-559	42/28/7	5-cell cavity, doublet
HB 650 $\beta=0.9$	650	559-3000	152/38/19	5-cell cavity, doublet

CAVITY DESIGNS

The 3 GeV linac includes five distinct cavity types as listed in Table 1. These cavities span the velocity range $\beta=0.11$ to $\beta=0.9$. The linac will utilize 82 single-spoke cavities at 325 MHz and 194 elliptical cavities at 650 MHz.

325 MHz Single-Spoke Cavities

There are three different single-spoke cavities: SSR0, SSR1 and SSR2, having velocity factors $\beta=0.11$, 0.22, and 0.4, respectively. The SSR1 cavity was designed and prototyped in the context of the High Intensity Neutrino Source (HINS) program at Fermilab. Two prototypes have already been built and tested as later described. Ten additional SSR1 cavities are under production at Niowave/Roark. The first of these has been delivered; the remainder are expected this year.

The SSR0 cavity design is challenging in that it has the tightest lattice requirements and the highest inherent sensitivity to microphonics due to its small accelerating gap length. The design of the SSR0 cavity along with its helium vessel is nearly complete [4,5], and it is planned to

*Work supported by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.

initiate procurement of 1-2 SSR0 prototypes later this year.

The electromagnetic design of the SSR2 cavity is complete. Mechanical design has not yet started. Further development of this cavity design will commence next year.

650 MHz Elliptical Cavities

There are two different five-cell elliptical cavities planned for Project X: $\beta=0.61$ and $\beta=0.9$. The electromagnetic designs of the cavities are complete with the exception of HOM couplers [6,7]. Single-cell $\beta=0.61$ cavities are being prototyped at Jefferson Lab. $\beta=0.9$ single-cell prototypes are in production at Advanced Energy Systems. The $\beta=0.61$ cavities will be processed and tested at Jefferson Lab whereas the $\beta=0.9$ cavities will be processed and tested in a collaboration between Fermilab and Argonne National Laboratory (ANL). Primary features of the cavities include a large bore of 100 mm and conservative peak magnetic fields of 70 mT. Mechanical designs of the five-cell cavities are in progress [8]. Procurement of 1-2 prototype five-cell $\beta=0.9$ cavities will be initiated later this year.

CAVITY TEST RESULTS

Two prototype SSR1 cavities have been tested in the Vertical Cavity Test Facility (VCTF) at Fermilab. The buffered chemical polishing (BCP) and high-pressure rinsing (HPR) of the cavities was performed at ANL as part of the Fermilab-ANL collaboration on superconducting cavity processing and testing. These cavities both exceeded their design specifications by roughly a factor of two in gradient. Peak surface magnetic fields of ~ 130 mT were achieved in at test at 2 K [9]. Subsequent to completion of vertical testing, one of the cavities was equipped with a stainless steel helium vessel, and outfitted with a cavity tuning system and RF power coupler. This cavity was tested at Fermilab in the Spoke Cavity Test Cryostat (SCTC), which is presently capable of 4.2 K operation. It will be upgraded for 2 K operation within the next year. The cavity has been tested in the SCTC under both continuous-wave and pulsed conditions, greatly exceeding performance specifications in both cases, as reported by Madrak et al. [10].

CRYOMODULE DESIGNS

325 MHz Cryomodules

Conceptual design work is underway for two types of cryomodules: 325 MHz cryomodules [11] for SSR0, SSR1 and SSR2 cavities and 650 MHz cryomodules [12] for LB650 and HB650 cavities. The three variants of 325 MHz cryomodules, although containing different numbers and types of cavities and magnets, will be designed to maximize commonality and minimize the quantity of distinct subcomponents. The same principle will be applied in the design of the 650 MHz cryomodules. The cryomodule design work is being

conducted collaboratively with participation from colleagues at Jefferson Lab, Raja Ramanna Centre for Advance Technology (RRCAT) and Variable Energy Cyclotron Centre (VECC).

The SSR0 cryomodule at the low-energy end of the linac is challenging in that it contains the largest number of components and is therefore the longest cryomodule in the linac. The lattice calls for 18 cavities and 18 superconducting solenoids, with a maximum cavity-to-cavity spacing of 610 mm. This results in a cryomodule length greater than 10 m. In comparison, the European XFEL cryomodule has a length of about 12 m and contains significantly fewer elements: eight 1.3 GHz superconducting cavities and one superconducting quadrupole. The lattice requires minimal spacing between the SSR0 and SSR1 cryomodules further complicating their designs. Therefore it is planned to design, construct and test a prototype SSR cryomodule with 3-4 cavities of either SSR0 or SSR1 type, depending on cavity availability. The conceptual design of the prototype cryomodule is shown in Figure 2.

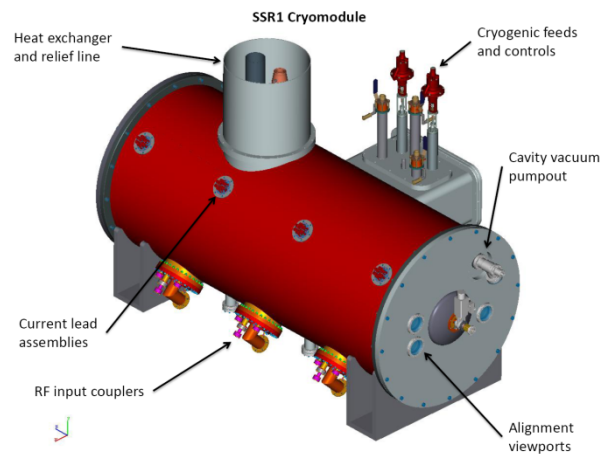


Figure 2: Prototype 325 MHz cryomodule layout.

650 MHz Cryomodules

The conceptual design of the 650 MHz cryomodules calls for eight cavities per cryomodule for an overall length of 12 m. The number of cavities per cryomodule is based on a practical heat load limit of 250 W to the 2 K circuit per cryomodule. This limit is based primarily on sizing considerations for the helium piping and heat exchanger. It is planned to follow the layout of the European XFEL cryomodule, where the cavity string hangs from a 300 mm gaseous helium return pipe. The helium pipe in turn will hang inside the 1.2 m diameter vacuum vessel from three conventional support posts. A cross section of the cryomodule is shown in Figure 3.

Segmentation

The Project X linac will feature fine cryogenic segmentation, similar to the Spallation Neutron Source (SNS) and CEBAF linacs, where each cryomodule is a stand-alone object that can be thermally cycled

independent of the rest of the linac. In the case of the Project X high-beta 650 MHz cryomodules, the fine segmentation is necessitated by the high heat load. The segmentation in the remainder of the linac is based on maintenance considerations and the need to have manageable-sized cryomodules. Thus it is planned to have 29 stand-alone cryomodules in the 3 GeV linac, as listed in Table 1.

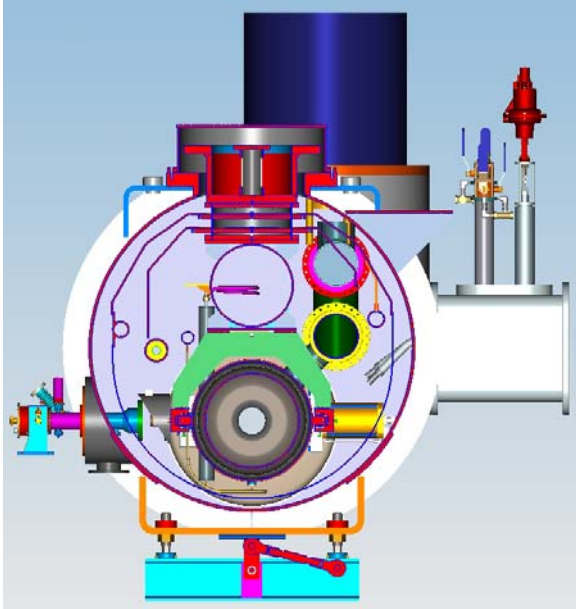


Figure 3: Cross section of 650 MHz cryomodule.

Auxiliary Components

The RF power couplers [13] and cavity tuning systems are being developed along with the cavities and cryomodules. Each cavity will have a slow frequency tuner driven by a stepping motor and a fast piezoelectric tuner that will be used to mitigate microphonics caused by ambient vibrations and helium bath pressure fluctuations. Pischankov and Schappert have successfully demonstrated sophisticated microphonics compensation on a prototype SSR1 cavity as well as a variety of 1.3 GHz cavities [14,15].

CONCLUSION

The cavity and cryomodule designs for Project X are underway and consistent with the baseline design of the accelerator complex. The prototype SSR1 cavities have shown excellent performance in vertical dewar and horizontal cryostat testing. Prototype single-cell 650 MHz cavities are in production, and it is planned to order five-cell prototypes later this year. The SSR0 cavity design is well-developed and will also be released for prototyping this year. Cryomodule conceptual design work has identified baseline configurations that will be further developed over the next 1-2 years.

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