OVERVIEW OF PROJECT X SUPERCONDUCTING RF CAVITIES AND CRYOMODULES*

T. Khabiboulline#, M. Champion, C. M. Ginsburg, and V. Yakovlev, Fermilab, Batavia, IL, USA

Abstract

The Project X Linac is based primarily on superconducting RF technology starting from a low beam energy of approximately 2.5 MeV up to the exit energy of 8 GeV. The Linac consists of 162.5 MHz half-wave cavities, two families of 325 MHz single-spoke cavities, and two families of 650 MHz elliptical cavities - all operating in continuous-wave mode - up to a beam energy of 3 GeV. The beam is further accelerated up to 8 GeV in a pulsed mode ILC-like Linac utilizing 1.3 GHz cavities. In this paper we will give an overview of the design and status of the Project X superconducting RF cavities and cryomodules.

INTRODUCTION

Project X is a proposed multi-MW proton accelerator facility at Fermilab based on an H- linear accelerator using superconducting RF technology; the schematic layout of the complex is shown in Fig. 1. The 3 GeV Project X linear accelerator (linac) provides a continuous-wave (CW) 3 GeV 1 mA H- beam to an experimental area, and is injected into a pulsed linac for further acceleration to 8 GeV and injection into the Main Injector. These beams will support a variety of experiments in kaon, muon, nuclear, and neutrino physics [1-3]. The 3 GeV linac will use superconducting 162.5MHz half-wave resonators (HWR), 325 MHz single-spoke cavities (SSR), and 650 MHz elliptical cavities. The 3-to-8 GeV linac will use 1300 MHz Tesla-type elliptical cavities. Six distinct cavity designs are planned spanning the geometric phase velocity range from β_G=0.11 to β_G=1. These cavities will be assembled into four different types of cryomodules. The HWR cryomodule will be designed and build by ANL. All cavities will operate at a temperature of 2.0 K. The designs of the cavities and cryomodules for the 3 GeV linac are in progress. The 3-8 GeV pulsed linac will take advantage of the well-developed 1300 MHz Tesla-type cavities in ILC-like cryomodules. The remainder of this paper will focus on the development of the new cavities and cryomodules for the CW 3 GeV linac; the main parameters of the linac sections are listed in Table 1.

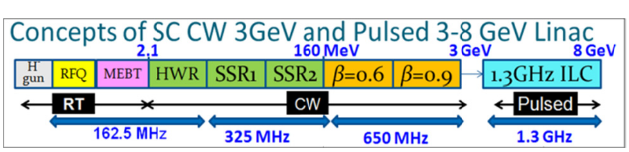


Figure 1: Schematic layout of the Project X accelerator complex.

* Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy
#khabibul@fnal.gov

Table 1: Parameters of the Project X linac sections

Section	Frequency (MHz)	Energy (MeV)	#cavities/ focusing elements/ cryomodules	Component Type
HWR β=0.11	162.5	2.1-10	8/8/1	Half Wave Resonator, solenoid
SSR1 β=0.22	325	10-32	16/10/2	single-spoke cavity, solenoid
SSR2 β=0.47	325	32-160	36/20/4	single-spoke cavity, solenoid
LB 650 β=0.61	650	160-520	42/14/7	5-cell cavity, doublet
HB 650 β=0.9	650	520-3000	152/38/19	5-cell cavity, doublet
ILC 1.3 β=1.0	1300	3000-8000	224/28/28	9-cell cavity, quadrupole

CAVITY DESIGN AND PERFORMANCE

The 3 GeV linac includes five distinct cavity types, spanning the geometric velocity factor range β_G = 0.11 to β_G = 0.9, with 8 half-wave resonators at 162.5 MHz, approximately 50 single-spoke cavities at 325 MHz and 200 elliptical cavities at 650 MHz.

162.5 MHz Half-Wave Resonators

ANL is developing β_G = 0.11 accelerating cavities for the energy range 2.1-10 MeV. The same frequency as for the RFQ was chosen to increase the energy gain per cavity and reduce the number of cavities. The latest design of the HWR includes a new donut shaped spoke aperture, which allows a reduction of the quadrupole component of the accelerating E-field and increases the shunt impedance from 198 Ω to 262 Ω compared to the initial race-track shape [4].

325 MHz Single-Spoke Cavities

Two single-spoke cavities: SSR1 and SSR2, have geometric velocity factors β_G=0.22, and 0.4, respectively. The cavity designs are described in detail in [5].

The SSR1 cavity was designed and prototyped in the context of the High Intensity Neutrino Source (HINS) program at Fermilab. Three prototypes have already been built and tested with encouraging results. Examples of cavity performance are shown in Fig. 2. The three prototype SSR1 cavities were tested in the Vertical Cavity Test Facility (VCTF) at Fermilab. 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. Two cavities exceed the Project X design specification for gradient. Peak surface magnetic fields of ~130 mT were achieved in a 2K test [6-7]. After vertical test, one of the cavities was welded into 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 Facility (SCTF), which is currently capable of 4.5 K operation and will be upgraded for 2 K operation within this year. The cavity has been tested under both CW and pulsed conditions, greatly exceeding performance specifications in both cases [8].

The first two SSR1's were built by Zanon and Roark, respectively. Ten additional SSR1 cavities are in progress at Niowave/Roark. The first six of these have been delivered; the remainder are expected this year. In addition, two cavities are being fabricated by our Project X collaborators at IUAC (India).

The SSR1 was designed for a pulsed machine; to optimize it for use in a CW machine, it was necessary to reconsider the frequency sensitivity to helium bath pressure variations. A new helium vessel, coupled to the end wall of the cavity, was designed to reduce the cavity df/dP to less than 5 Hz/Torr.

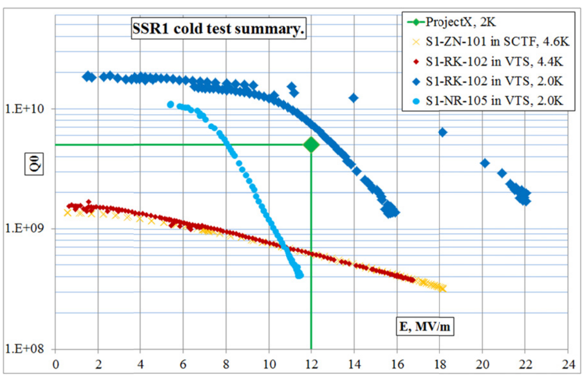


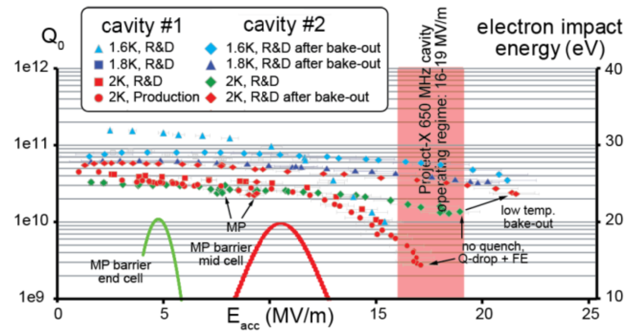
Figure 2: Performance of SSR1 cavities in bare (VTS) and dressed (SCTF) cavity tests, at 2K and ~4.5K.

The electromagnetic design of the SSR2 cavity for the β_G=0.4 section is complete; the mechanical design is preliminary and underway.

650 MHz Elliptical Cavities

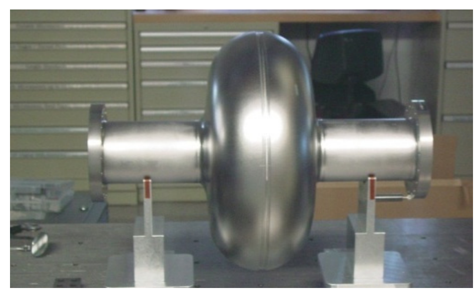
Two five-cell elliptical cavities are planned for Project X: β_G = 0.61 and β_G = 0.9 [9]. The anticipated heat loads for the 650 MHz section lead to stringent requirements on cavity unloaded quality factor Q_0. Each cryomodule for these cavities must dissipate no more than 250W average and peak power at 2K [10]; this leads to a requirement for cavities, using some assumptions about the power dissipation of other cryomodule components, of <35W per cavity for β_G = 0.61 cavities and <25W per cavity for β_G = 0.9 cavities.

As part of the Fermilab-JLab Project X collaboration, two prototype single-cell 650 MHz β_G = 0.61 cavities were designed, fabricated, processed and tested by JLab, with excellent results [11, 12]. The cavities were processed with standard techniques, including bulk BCP, 600C for 10 hours hydrogen degassing, and another light BCP (no electropolishing). For this cavity, the 35W power requirement corresponds to Q_0>8.8E9 at 2K for E_{acc}=16 MV/m and Q_0>1.3E10 at 2K for E_{acc}=19 MV/m. The test results, shown in Fig. 3, demonstrate the achievement of the Q_0 requirement at 16 MV/m for cavity #2. Further surface processing is likely to bring both cavities into conformance with the performance requirement, and electropolishing may not be required. Further mechanical studies will be required to extend this design to a 5-cell cavity which is stiff enough reduce sensitivity to helium bath pressure variations, Lorentz force detuning, and microphonics, but still tunable.



es. A
ndary

In addition, a Fermilab electromagnetic design for one-cell and 5-cell β_G=0.61 cavities was completed [13].



es.

The design for the 650 MHz β_G = 0.9 cavities is complete [14]. Six prototype single-cell cavities have been received from industry and two five-cell 650 MHz β_G=0.9 cavities have been ordered, Fig. 4. These cavities will be processed and tested at Fermilab/ANL facilities. Primary features of the cavities include a large beam pipe aperture of 100 mm and conservative peak magnetic field of 70 mT. The more stringent power dissipation requirement is likely to require careful optimization of surface processing. The prototype cavities do not have HOM couplers [15].

Our Project X collaborators at RRCAT (India) and VECC (India) are working with us on the fabrication of the 650 MHz cavities as well.

CRYOMODULE DESIGNS

The cryomodules are in the conceptual design stage. Segmentation of the linac, which determines the number of cavities per cryomodule and the cavity spacing, is based on lattice requirements, heat load, and reliability issues. The cryomodule design work is being conducted with collaborative participation from colleagues at ANL, JLab and RRCAT.

162.5 MHz Cryomodule

ANL is working on a 162.5 MHz eight-cavity cryomodule. Conceptual drawings have been developed for the cold mass. A heat exchanger and J-T valve are being incorporated into the common vessel. The final design of the vacuum vessel is being developed.

325 MHz Cryomodules

Conceptual design work is underway for 325 MHz cryomodules [14] for the SSR1 and SSR2 cavities. The two types of 325 MHz cryomodules, although containing different numbers and types of cavities and focusing elements, shall have as common a design as possible. To minimize project risk, a prototype SSR1 cryomodule will be designed, constructed and tested [16].

650 MHz Cryomodules

The conceptual design (Fig. 5) of the 650 MHz cryomodules is also underway [9]; the two types of cryomodules, while containing different numbers and types of cavities and focusing elements, will be made as similar as possible. Most of the design work so far is for the β_G = 0.9 cryomodule, which contains 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, which in turn is based primarily on sizing considerations for the helium piping and heat exchanger. The baseline design concept includes cryomodules closed at each end, individual insulating vacuums, with warm beam pipe and magnets in between cryomodules, so that individual cryomodules can be warmed up and removed while adjacent cryomodules remain cold.

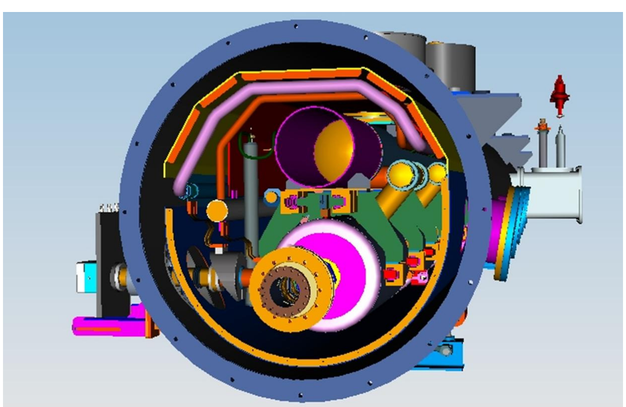


Figure 5: Cross section of 650 MHz cryomodule concept.

CONCLUSIONS

The cavity and cryomodule designs for the Project X 3 GeV linac are underway. The cavity prototypes built so far are performing to requirements: SSR1 cavities have shown excellent performance in vertical Dewar and horizontal cryostat testing, and initial vertical test results from β_G = 0.61 single-cell 650 MHz cavities have demonstrated the feasibility of the design for 5-cell cavities. Cavity design, fabrication, and test are underway to confirm designs for the complement of cavities required for Project X within the next 1-2 years. Cryomodule conceptual design work has identified baseline configurations that will also be further developed over the next couple of years and a prototype cryomodule will be built to confirm the design.

ACKNOWLEDGEMENTS

We are grateful to our Fermilab, national and international Project X collaborators for their hard work and excellent contributions to cavity and cryomodule development for Project X.

REFERENCES

[1] R. Kephart et al., “Project X Functional Requirement Specification,” Project X Document 658-v7 (2011), http://projectx-docdb.fnal.gov.

[2] S. Holmes et al., “Project X: News, Strategy, Meeting Goals,” Project X Document 1026-v2 (2012), http://projectx-docdb.fnal.gov.

[3] S. Nagaitsev et al., “Project X – New Multi Megawatt Proton Source at Fermilab,” PAC’11, New York City, FROBN3.

[4] P. Ostroumov. “HWR Cryomodule Development”, Project X Collaboration meeting, April 10-12, 2012

[5] L. Ristori et al., “Design of SSR1 Spoke Resonators for PXIE,” WEPPC057, this conference.

[6] M. Champion, “Accelerator and Injector Systems – SRF Activities,” Project X Document 812-v1 (2011), http://projectx-docdb.fnal.gov.

[7] T. Khabiboulline et al., “High Gradient Tests of the Fermilab SSR1 cavity,” WEPPC052, this conference.

[8] R. Madrak et al., “First High Power Pulsed Tests of a Dressed 325 MHz Superconducting Single Spoke Resonator at Fermilab,” PAC’11, New York City, TUP076.

[9] C.M. Ginsburg et al., “Functional Requirement Specification: 650 MHz Superconducting RF Cavities,” http://projectx-docdb.fnal.gov.

[10] T. Peterson et al., “650 MHz Cryomodules for Project X at Fermilab – Requirements and Concepts,” MOPO003, SRF 2011.

[11] P. Kneisel et al., “Preliminary Test Results from 650 MHz Single Cell Medium Beta Cavities for Project X,” MOPO070, SRF 2011.

[12] F. Marhauser et al., “Design, Fabrication and Testing of Medium-Beta 650 MHZ SRF Cavity Prototypes for Project-X,” MOPC114, IPAC’11.

[13] V. Yakovlev et al., “Concept EM Design of the 650 MHz Cavities for the Project X,” TUP089, PAC’11, New York City.

[14] S. Barbanotti et al., “Status of the Mechanical Design of the 650 MHz Cavities for Project X,” TUP069, PAC’11, New York City.

[15] V. Yakovlev et al., “HOMS in the Project X Linac,” TUP088, PAC’11, New York City.

[16] T. Nicol et al., “SSR1 Cryomodule Design PXIE,” WEPPD005, this conference.

ISBN 978-3-95450-115-1