FERMILAB-CONF-15-630-AD
Proceedings of IPAC2015, Richmond, VA, USA TUPJE080

FIRST BEAM AND HIGH-GRADIENT CRYOMODULE COMMISSIONING RESULTS OF THE ADVANCED SUPERCONDUCTING TEST ACCELERATOR AT FERMILAB*

D.J. Crawford#, C. Baffes, D. Broemmelsiek, K. Carlson, B. Chase, E. Cullerton, J. Diamond, N. Eddy, D. Edstrom, E. Harms, A. Hocker, C. Joe, A. Klebaner, M. Kucera, J. Leibfritz, A. Lumpkin, J. Makara, S. Nagaitsev, O. Nezhevenko, D. Nicklaus, L. Nobrega, P. Piot, P. Prieto, J. Reid, J. Ruan, J. Santucci, W. Soyars, G. Stancari, D. Sun, R. Thurman-Keup, A. Valishev, A. Warner, S. Wesseln, Fermilab, Batavia, IL 60510, USA

Abstract

The advanced superconducting test accelerator at Fermilab has accelerated electrons to 20 MeV and, separately, the International Linear Collider (ILC) style 8-cavity cryomodule has achieved the ILC performance milestone of 31.5 MV/m per cavity. When fully completed, the accelerator will consist of a photoinjector, one ILC-type cryomodule, multiple accelerator R&D beamlines, and a downstream beamline to inject 300 MeV electrons into the Integrable Optics Test Accelerator (IOTA). We report on the results of first beam, the achievement of our cryomodule to ILC gradient specifications, and near-term future plans for the facility.

INTRODUCTION

A superconducting radio frequency (SRF) accelerator test facility is currently under construction at Fermilab. Once complete, the accelerator will consist of a photoinjector front-end, two superconducting booster cavities, a 50 MeV beamline, a beam acceleration section consisting of one ILC-type cryomodule, multiple downstream beamlines, the IOTA storage ring with various diagnostics to conduct beam tests, and a high-power beam dump. This paper describes the commissioning effort of the facility to date. [1]

Front-end

The front-end consists of a 1.5 cell normal conducting RF Gun resonating at 1.3 GHz with a peak accelerating gradient of up to 45 MV/m, a cesium telluride (Cs_2Te) cathode for photoelectron production, a 3 ps pulsed 263 nm ultra-violet (UV) laser delivery system, and a diagnostic area for measuring the charge and spot size of the photoelectron beam. [2] The UV laser system is tuneable from 1 to 3000 micro-bunches within a 1 ms bunch train at a maximum 5 Hz repetition rate. Two solenoid magnets, each capable of a peak field of 0.28 T at 500 A, surround the RF Gun cavity. The main solenoid provides the appropriate field for focusing the electron beam to the booster cavities. The bucking solenoid cancels the magnetic field from the main solenoid at the photocathode surface in order to minimize beam emittance.

Booster Cavities

There are 2 small cryomodules after the front-end known as Capture Cavity 1 (CC1) and Capture Cavity 2 (CC2). Each of these cryomodules contains one 9-cell L-band cavity operating at 1.3 GHz, driven by a 300 kW klystron, and capable of average accelerating gradients >22 MV/m. These cavities will also be used to “chirp” the beam, i.e. generate a time-momentum correlation, in preparation for bunch compression in the chicane. Downstream of these cavities is space allotted for a future SRF 3.9 GHz cavity intended to be used for bunch linearization during bunch compression. [3]

Currently, CC2 is installed and CC1 will be installed upstream of CC2 during summer 2015 and will allow for a maximum beam energy of 50 MeV.

50 MeV Beamline

After CC2, the electron beam enters the 50 MeV beamline. There is a quadrupole doublet to control the beam size for emittance measurements, a matching section into a chicane, a 4-dipole chicane for bunch compression (R56 = -0.18 m), and a matching section into a 22.5° vertically downward bending dipole. This dipole, upstream of the absorber, will serve as the low energy spectrometer. The 50 MeV beam absorber is capable of accepting up to 550 W of beam power. [3, 4]

The beamline also consists of 13 horizontal and vertical trim dipole magnets, 6 transverse profile monitors (TPM), 19 beam position monitors (BPM), 2 toroids, 2 wall current monitors (WCM), and 8 beam loss monitors connected to the Machine Protection System (MPS). Each TPM contains either a 100 µm thick cerium-doped yttrium aluminum garnet (YAG) screen or a 100 µm thick lutetium yttrium oxyorthosilicate (LYSO) screen. Each TPM also contains an optical transition radiation (OTR) foil of 25 µm or 1 µm thick, and a 1951 USAF optical resolution target for pixel and resolution calibration. The TPM in the chicane has a slit mask experiment installed in the OTR position.

Installation of the 50 MeV beamline was completed earlier this year. A schematic beamline is shown in Fig. 1.

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

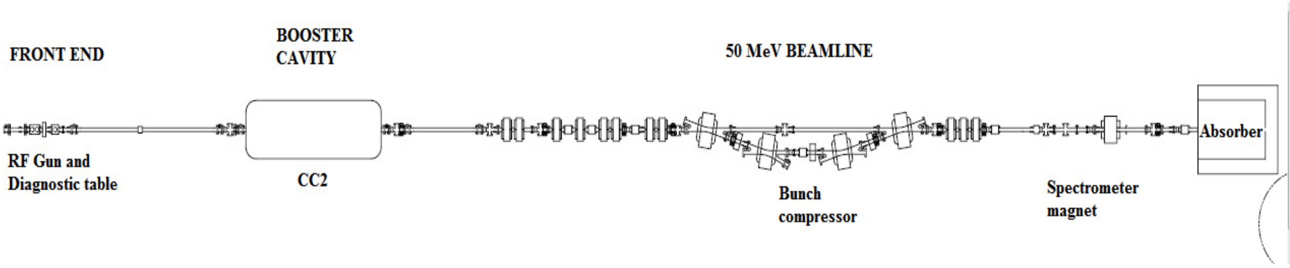

Figure 1: Schematic of beamline elements.

Cryomodule

The basic accelerating unit for the ILC is an SRF cryomodule that houses eight or nine 9-cell 1.3 GHz niobium cavities. The cavities are required to operate with an accelerating gradient of 31.5 MV/m and have an unloaded quality factor of $Q_0 \geq 1 \times 10^{10}$. [5]

Fermilab has constructed an ILC style cryomodule containing 8 cavities. A single 1.3 GHz 5 MW klystron drives all of the cavities by means of variable tap-offs in a waveguide distribution system. Each cavity proved to operate at greater than 35 MV/m when tested in horizontal and vertical test stands. Cryomodule RFCA002, more commonly known as CM2, was installed in April 2013 and 2 K operation began November 2013. [6] Figure 2 shows CM2 inside the accelerator enclosure with the waveguide distribution system attached.

Figure 2: CM2 with waveguide distribution system.

50 MEV BEAMLINE COMMISSIONING

The UV laser transport system and RF Gun commissioning were completed in 2013 and first photoelectrons to the diagnostic table Faraday cup was achieved on June 20, 2013.

Prior to commissioning the beamline, all dipole and quadrupole field polarities were verified. Remote control of each TPM was tested and optical calibration targets were imaged in order to set pixel calibrations. Beam toroid and BPM hardware scalings were determined and loaded into software.

Commissioning of the 50 MeV beamline began on March 26, 2015. Quadrupole and dipole magnet currents, determined through a simulation in the program Elegant, were loaded into the power supplies. The RF Gun was set to 42 MV/m peak accelerating gradient. CC2 was reconditioned for operation at 15 MV/m. The UV laser was set to provide 40 micro-bunches per pulse train. A 250 picocoulomb per bunch beam was established to the Faraday cup on the Diagnostic table. The cup was remotely retracted and a 20 MeV electron beam was established to the low energy absorber on the morning of March 27, 2015. Figure 3 shows an image from a YAG crystal in a TPM downstream of the spectrometer magnet.

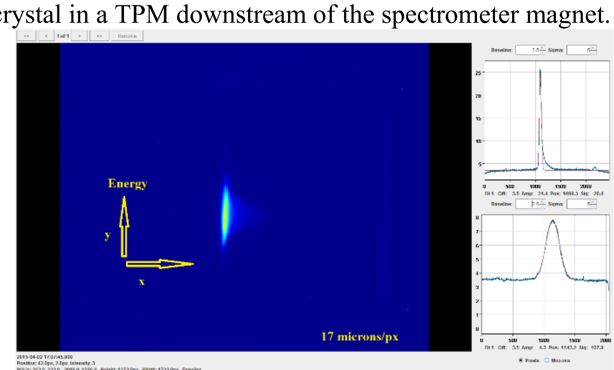

Figure 3: YAG image from the TPM downstream of spectrometer magnet, upstream of the low energy absorber.

CYROMODULE COMMISSIONING

A testing procedure was developed from a previously installed ILC-type cryomodule, known as CM1. The cavities were tested one at a time. [6] The procedure is summarized as:

- Cooldown the cavity and tune it to 1.3 GHz
- Set the motorized input coupler to a nominal position that is centered around $Q_L = 3.5 \times 10^6$
- Calibrate the forward, reflected, and transmitted power signals by using a few kW of forward power
- Perform on-resonance cavity and coupler conditioning with pulse lengths ranging from 20 µs to 1.3 ms
- Recalibrate forward, reflected, and transmitted power signals with 100 kW of forward power
- Determine maximum operating gradient
- Implement the Lorentz force detuning compensation adaptive feed-forward system which keeps the cavity in resonance through the entire pulse
- Perform measurements of X-ray and dark current as a function of gradient
- Measure the dynamic heat load as a function of gradient in order to determine Q_0

Once all cavities were individually tested, the waveguide distribution system was connected to all of the cavity couplers and the output of the 5 MW klystron. All cavities were then simultaneously powered and the gradients were increased. As seen from Fig. 4, all but one, cavity 6, were able to reach the administrative limit of 31.5 MV/m. Cavity 6 was detuned slightly and the modulator voltage was increased from 7.9 kV to 8.1 kV. On 10/03/2014, CM2 ran at an average accelerating gradient of 31.5 MV/m per cavity with an overall accelerating voltage of 252 MV.

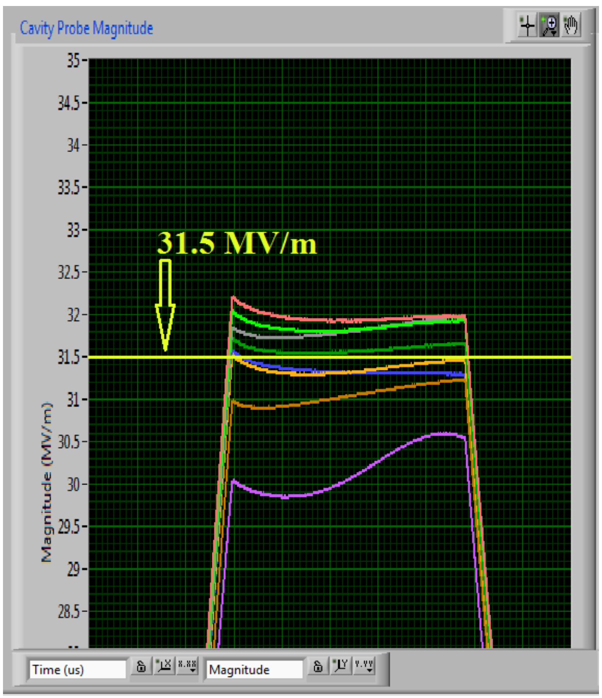

Figure 4: CM2 gradients for all cavities simultaneously powered. Average accelerating gradient is 31.5 MV/m with an overall accelerating voltage of 252 MV.

ACKNOWLEDGMENTS

The authors recognize the diverse and capable expertise of the technical staffs of Fermilab's Accelerator and Technical divisions. The crews providing mechanical, electrical, and RF support are especially noted.

CONCLUSIONS

Commissioning of the 50 MeV beamline continues. Transfer matrix measurements of CC2 were recently completed and the data is being analyzed. MPS loss monitor calibrations are underway and have the highest priority.

The bunch compressor will be brought online in the coming months once chicane dipole magnet currents are input into the MPS. Once this happens a micro-bunching experiment, utilizing a tungsten slit mask for beam shaping, can begin gathering data.

CC1 and its associated cryogenic hardware will be installed summer 2015. During this long shutdown additional instrumentation will be installed into the 50 MeV beamline. Three slit mask stations will be installed so that beam emittance measurements can be made. A goniometer for a diamond X-ray channelling experiment will be installed upstream of the spectrometer magnet.

CM2 has met the ILC specification of a 31.5 MV/m per cavity average gradient with a 1.6 ms pulse width and 5 Hz operation. A peak accelerating voltage of 252 MV was achieved for this cryomodule. The cryomodule is currently undergoing a study to determine the quench limit for each cavity.

REFERENCES

[1] J. Ruan, et al, "Commissioning Status of the Advanced Superconducting Test Accelerator at Fermilab," IPAC'14, Dresden, Germany, June 2014.

[2] D. J. Crawford, et al, "Assembly and Installation of the UV Laser Delivery and Diagnostic Platform and the Photocathode Imaging System for the ASTA Front-end," IPAC'14, Dresden, Germany, June 2014.

[3] M. Church (Editor), "Design of the ASTA Facility", Fermilab report beams-doc 4212 (2012).

[4] C. Baffes, et al, "ASTA Low Energy Absorber Thermal Analysis," Fermilab report beams-doc 4063 (2012).

[5] N. Phinney, N. Toge, N. Walker, et al, "International Linear Collider Reference Design Report Volume 3," 2007.

[6] A. Hocker, et al, "Results from RF Tests of the First US-Built High-Gradient Superconducting Cryomodule," IPAC'14, Dresden, Germany, June 2014.

ISBN 978-3-95450-168-7