FIRST OPERATION OF A SUPERCONDUCTING RF ELECTRON TEST ACCELERATOR AT FERMILAB*

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Abstract

A test accelerator utilizing SRF technology recently accelerated its first electrons to 20 MeV at Fermilab. Foreseen enhancements will make acceleration to 300 MeV possible at a maximum beam power of 80 kW. A summary of commissioning steps and first experiments as well as current beam parameters compared to design is presented. Plans for expansion and the future physics program are also summarized.

INTRODUCTION

The Fermilab Accelerator Science and Technology (FAST) facility was originally conceived to serve as, "a system test, with beam, of a complete ILC RF unit" [1]. Over time the purpose has changed, but the fundamental design of the injector section has remained more or less the same and is still envisioned to be a facility providing a high-brightness, high-intensity electron beam. The accelerator and its intended purposes have been extensively described [2, 3].

The FAST injector as shown in Fig. 2 consists of

- A normal conducting photoinjector gun
- Two 'booster' SRF cavities
- A 50 MeV beam transport line including a bunch compressing chicane
- A Spectrometer magnet which bends the beam down by 22.5° into a
- Low energy beam absorber.

When fully completed, the electron accelerator will consist of the low energy section described above, one ILC-type cryomodule, accelerator R&D beamlines, and a high energy beamline able to inject up to 300 MeV electrons into the Integrable Optics Test Accelerator (IOTA) [4].

PHOTOINJECTOR GUN

The RF photocathode electron gun is identical to the guns developed at DESY Zeuthen (PITZ) for the FLASH facility [5]. It is a normal conducting 1-½ cell 1.3 GHz RF cavity operated in the TM010 π-mode, with a Q_L of 11,700, and driven by a 5 MW klystron. The gun is capable of average DC power dissipation of 20 kW, and a temperature feedback system will regulate cooling water temperature to less than ±0.02° C for good phase stability. The gun is routinely operated at peak gradients of 40-45 MV/m with an output beam kinetic energy of 4.5 MeV.

The RF Gun cavity is immersed in two solenoid magnets each capable of a peak field of 0.28 T at 500 A. The main solenoid provides the appropriate field for focusing the electron beam to the booster cavities while the bucking solenoid cancels the magnetic field from the main solenoid at the photocathode surface in order to minimize beam emittance.

The photocathode is a 10 mm diameter molybdenum disk coated with Cs_2Te with a 5 mm diameter photosensitive area. It is illuminated by 263 nm wavelength laser light which is directed onto the photocathode by a 90° off-axis mirror downstream of the RF coupler. A complete description of the gun and its early operation is previously documented [6].

SUPERCONDUCTING RF SYSTEMS

Two single cavity Superconducting RF Cryomodules comprise the accelerating section of the FAST injector. These are located immediately downstream of the gun as depicted in Fig. 1 and together will provide an accelerating voltage of order 50 MV.

Capture Cavity 1

The history and recent upgrade of Capture Cavity 1 (CC1) has been previously documented [7, 8]. Based on horizontal tests it is expected to operate at gradients up to 29 MV/m. With the upgrade work now completed, the cryomodule has been installed on the FAST beam line. Vacuum and cryogenics connections are being made and full integration into FAST is now in process. In anticipation of its resumption of operation, the 300 kW klystron previously used to drive it at has been relocated to FAST and is being re-commissioned there. CC1 re-commissioning and operation is expected to occur in late 2015 to early 2016.

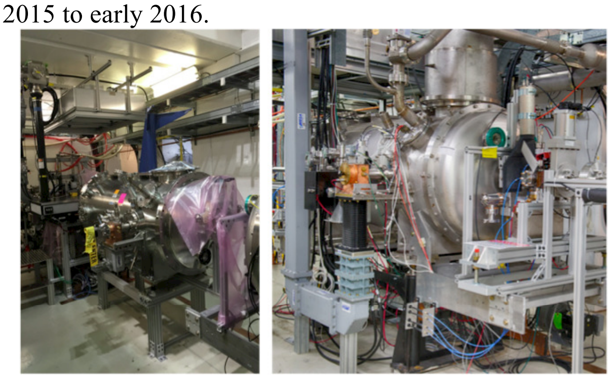

Figure 1: CC1 (left) and CC2 (right) installed in FAST.

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Capture Cavity 2

Capture Cavity 2 (CC2) has been in operation at FAST longer than any other component having first served as the heat load for cryogenic system commissioning. Its operation at FAST has been described previously [9]. For FAST injector commissioning it has routinely operated at a gradient of 16 MV/m and has demonstrated capability of operating at ~20 MV/m. Its gradient is presently limited by vacuum activity in both the coupler and cavity as well as by Lorentz Force Detuning (LFD). CC2 does have a fast tuner to compensate for LFD and this will be brought into operation in the near future.

BEAMLINE

The 50 MeV beam transport line immediately follows CC2. Here the electron beam passes through a quadrupole doublet for controlling the beam size for emittance measurements, a matching section, and then into a 4-dipole chicane for bunch compression (R56 = -0.18 m), and a matching section before reaching the spectrometer dipole magnet which bends it 22.5° downward to the beam absorber [10]. The 50 MeV beam absorber is capable of accepting up to 550 W of beam power [11,12].

Table 1: Typical FAST Operating Parameters

Parameter	Value	Units
Bunch charge	0.25	nC
Gun gradient	42	MV/m
CC2 gradient	16	MV/m
Beam energy	20	MeV
Bunch length	6-8	ps (rms)

In total, the beam line consists of 13 horizontal and vertical trim dipole packages, 6 transverse profile monitor (TPM) stations, 19 beam position monitors (BPMs), 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 line occurred from early 2014 to spring 2015 interspersed with periods of operating the Gun and CM-2. This work was expedited by constructing three girders and mounting the components on them external to the cave as they became available. This prefabrication work allowed much of the installation work to occur outside the cave independently of the operating schedule. Final alignment and vacuum work was done using portable clean rooms once all girders were in place.

In parallel with the physical installation, all of the necessary component check-out occurred and safety documentation was completed and approved.

BEAM COMMISSIONING

The ultraviolet laser, laser transport line, and gun have been operational since June 2013. With installation of all devices deemed necessary for first beam, each verified operational, and safety permissions given, the first attempts to systematically transport beam through CC2 and thence to the beam absorber began late in the day on 25 March 2015. By the end of the next day electrons had been verified to pass through and be accelerated by CC2 reaching the spectrometer magnet. On the morning of the third day of commissioning there was confirmation of beam to the absorber at the end of the line as shown in Figs. 3, 4, and 5. Commissioning was necessarily done with as low an intensity as practical using the parameters listed in Table 1. The RF Gun was set to a peak accelerating gradient of 42 MV/m. CC2 was reconditioned for operation at 15 MV/m. Nominally the UV laser was set to provide 40 micro-bunches per 1 Hz pulse train with 250 pico-Coulomb per bunch.

Since this the achievement of first beam, its properties have been measured and diagnostics systems have been calibrated and brought into operation. Early experiments have also begun. A short list of studies on the FAST beam includes:

- Energy & Energy Spread
- Quantum Efficiency (QE) vs. Charge
- CC2 transfer function measurement
- Preliminary Emittance
- Chicane commissioning
- Bunch length measurements with a streak camera
- Longitudinal bunch profile studies
- Ceramic gap monitor early commissioning
- Machine Protection System commissioning, tests and development.

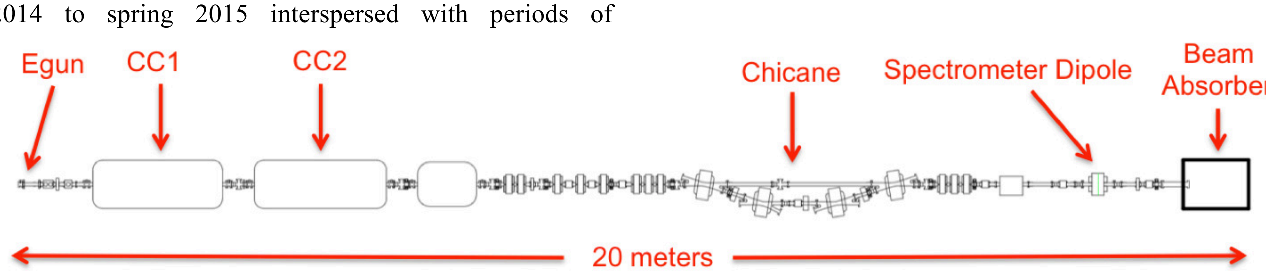

Figure 2: FAST Injector Layout.

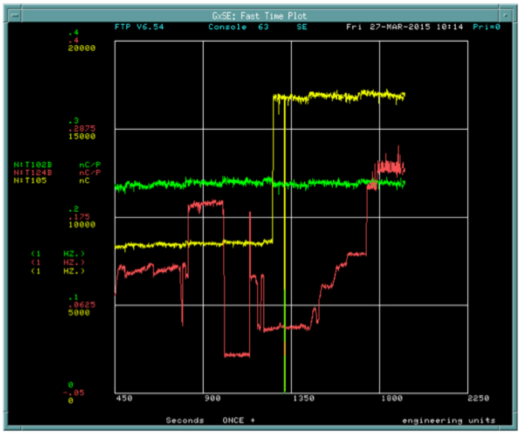

Figure 3: Toroids along the FAST 50 MeV beam line recording first electrons to the beam absorber. The red trace is T124B located immediately after the spectrometer magnet. Measured beam current is ~0.2 nCoulombs.

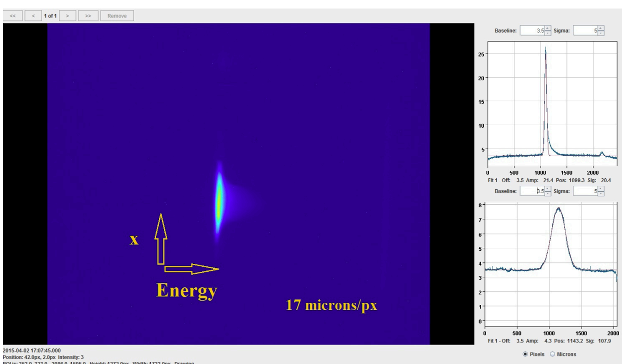

Figure 4: YAG image of first 20 MeV electrons in FAST. The detector is located between the spectrometer magnet and beam absorber.

CURRENT SITUATION & FUTURE PLANS

FAST is currently in shutdown and its SRF systems, including CM-2, at room temperature to facilitate installation of CC1 and integrate it to the cryogenics infrastructure. Once installation is complete, cool down and commissioning of CC1 will occur with the goal of achieving 50 MeV electrons through the FAST injector.

Once this is completed, expected in spring 2016, the high energy beam line from CM-2 to the beam absorber at the very end of FAST will be installed. The goal for FY2016 is then to realize 300 MeV electrons through CM-2 and the high energy beam transport line beyond. IOTA installation will occur in parallel with the expectation of first injection of electrons into IOTA in FY2017.

SUMMARY

The FAST facility at Fermilab has now been made operational, accelerating its first electrons to 20 MeV by means of a superconducting RF cavity. In the coming months a second cavity will come on-line making 50 MeV operation possible. In the longer term the injector will be joined to CM-2 making energies up to 300 MeV possible. Its primary function as an electron injector for IOTA is expected to be realized in 2017.

Figure 5: Celebration of first 20 MeV electrons at FAST on 27 March 2015.

ACKNOWLEDGMENTS

This achievement is many years in the making and involved a large number of people both at Fermilab and elsewhere, many whom are no longer involved with the facility. The rapid achievement of first beam once installation was completed is a testament to the diligence and dedication of the FAST team.

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