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TM 6: Fractional Arc Test - beam through MLC & girder

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CBETA Technical Note 25
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Summary

On April 18 2018, the CBETA project achieved technical milestone 6, "Fractional Arc Test: beam through the Main Linac Cryomodule and prototype girder", which is also a major funding milestone. For this test the electron beam was accelerated to a final energy of 42 MeV in the Main Linac Cryomodule (MLC), before being passed through the first splitter beam line S-1 and through the first permanent magnet arc girder (PMA). The MLC contains six superconducting accelerating cavities; for this test only five of the six were powered due to a temporary fault in cavity number 5.

Details

Earlier measurements in the Fractional Arc Test individually calibrated the energy gain in each MLC cavity. After each cavity was turned on individually to a given uncalibrated setpoint, the phase of the cavity was varied from 0 to 360 degrees while monitoring the arrival times of the beam at the first beam position monitors (BPM) after the MLC. The beam was both accelerated and decelerated during this scan, depending on the phase, reflected by the variation in the arrival time due to the change of speed of the electrons. This variation was fitted to a detailed model of the MLC, producing best values for the calibrated set point of each cavity, as shown for example in Figure 1 for cavity 3. After all the cavities were individually calibrated we proceeded to send beam through the subsequent machine sections.

Initial work, preparing the RF in the MLC cavities for the beam test, began at 4:30 pm on April 18 and continued until 8:00 pm, after the CBETA area was roped off and locked up. Cavities were initially tuned in a klystron loop at a few MeV without microphonics compensation. The nominal setpoint for CBETA operation is 6 MeV per cavity. However, microphonics compensation enables significant larger voltages on stiffened cavities (2, 4 and 6). The cavity voltages were slowly raised to peak values of 6 MeV and 8 MeV in the unstiffened (1 and 3) and stiffened cavities (2, 4 and 6), respectively. Table 1 shows the cavity setpoints for operation with a total electron energy of 42 MeV and 36 MeV, including a contribution of 6 MeV from the injection cryomodule.

Total Energy	Cavity 1	Cavity 2	Cavity 3	Cavity 4	Cavity 5	Cavity 6
42 MeV	6	8	6	8	0	8
36 MeV	0	8	6	8	0	8

Table 1: Main linac cryomodule cavity settings during 42 MeV and 36 MeV operation. The energy of the beam out of the injection cryomodule is 6 MeV.

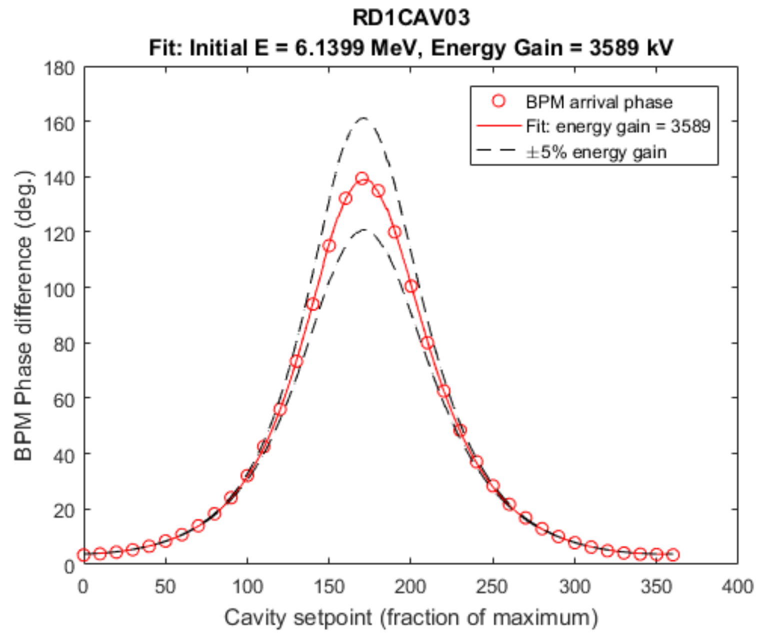

Figure 1: A typical example of beam position monitor arrival time as a function of cavity phase, for main linac cryomodule cavity 3.

After setting the MLC cavity voltages we turned on the injection cryomodule, the buncher, and the ion source gun, and restored the RF and magnet machine settings to their baseline setpoints, which were set a few days prior. The photoinjector laser was turned on, and the input currents of all of the magnets in the splitter line S-1 were scaled to their ideal 42 MeV values. A little dipole magnet tuning was required in order to place the beam near the center of the splitter BPMs. The beam passed all the way through the PMA girder after only a slight change of the current in the final electromagnet dipole before the girder.

Figure 2 (top) shows an image of the 42 MeV beam that was recorded on a viewscreen at the end of the PMA girder, with horizontal and vertical RMS beam sizes of about 0.39 mm and 0.25 mm – almost round. Beam was also passed through the PMA at a lower energy of 36 MeV, approximately the minimum possible for a single girder, as recorded in Figure 2 (bottom). As expected, the final beam was much larger horizontally (2.26 mm) than vertically (0.26 mm) at the lower energy, which is below the energy threshold of about 40 MeV predicted for stable orbits in a repeated set of PMA girders.

The beam current was increased to 30 nA after returning to a beam energy of 42 MeV, for a radiation survey of the perimeter of the CBETA area. Radiation levels only slightly above background were seen, allowing for daytime operation at these currents and energies. The beam was turned off at 9:30 pm, and the interior of the area was surveyed to check for residual radiation from activation of the beam stop. Slight activation was measured, well below the threshold that requires additional action to be taken. Radiation levels were back at background levels after 12 hours.

Many tests of the MLC and splitter line magnets were performed prior to April 18. However, this milestone is both the first successful test of the full MLC at the design energy gain, and also the first time that beam has been sent through the permanent magnet arc.

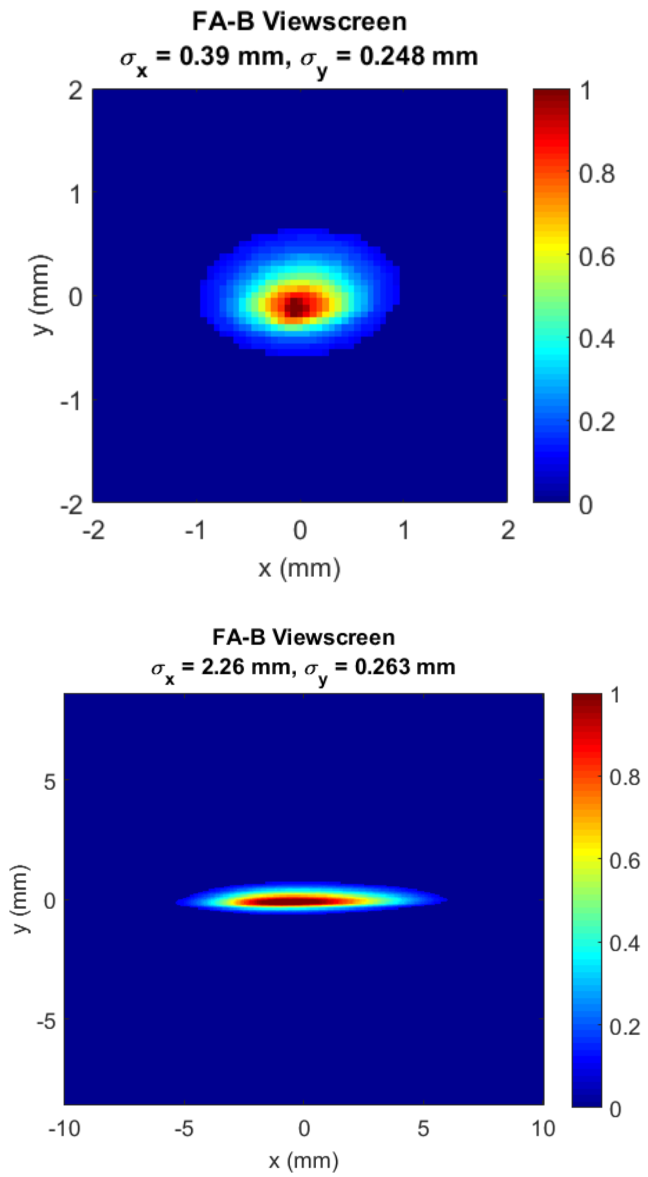

Figure 2: Images of the electron beam on a viewscreen at the end of the permanent magnet girder PMA at a total energy of 42 MeV (top) and 36 MeV (bottom).

Acknowledgements

It is thanks to the hard work, dedication and good humor of the entire CBETA collaboration team that technical milestone 6 was achieved in such a professional fashion. Thanks to everyone.