THE PERFORMANCE OF THE BEAM DIAGNOSTICS SYSTEMS FOR THE FERMILAB 400 MEV LINAC*

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ABSTRACT

A crucial component in the speedy commissioning of the 400 MeV Linac at Fermilab was the availability of good diagnostics on the first day of commissioning. Many lessons were learned during the startup, and these will be presented. The systems used in the new linac are: beam position monitors (BPMs), slow wire scanners, resistive wall-current monitors with a combined-function toroid beam-current readout, bunch-length detectors and loss monitors. Techniques and data for each of these systems are presented here.

INTRODUCTION

The Fermilab 400 MeV Linac (the Linac) has been upgraded from a 200 MeV linac with the addition of 60 m of side-coupled structure (SCS) cavities, operating at three times the gradient of the old 200 MeV linac [1]. There are 31 SCS sections in the high-energy linac (HEL), organized into seven 4-section "modules", a 16-cell buncher and a 4-cell vernier in the 116 MeV transition section and a 4-cell debuncher at 400 MeV near injection into the Booster synchrotron.

The HEL contains many new beam diagnostics systems. A schematic of the layout of these components is shown in Figure 1. The primary constraint in the design of the diagnostics has been the space allowed for these devices: the space between sections is 3βλ/2, which is only 0.263 m between sections 1 and 2 of Module 1. The broad features of the diagnostics systems are summarized in Table 1.

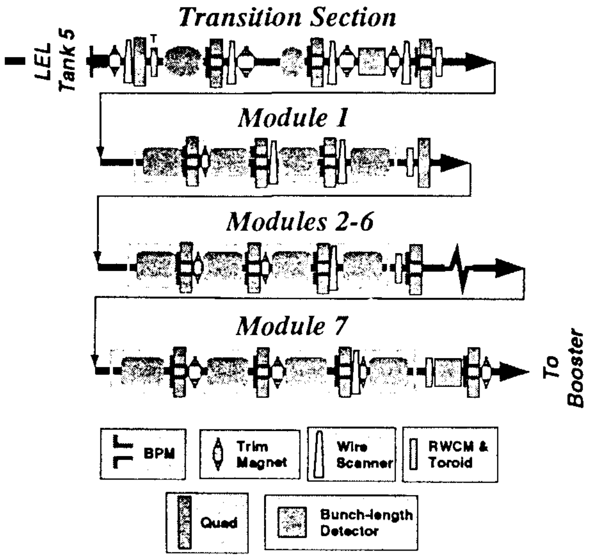

Figure 1., Schematic Layout of the Beam Diagnostics.

Device		#	Beam Parameter Measured
Beam Position Monitor	BPM	29	Position Phase Velocity
Loss Monitor	LM	31	Losses
Wire Scanner	WS	11	Transverse Emittance
Resistive Wall-Current Monitor	RWCM	8	Current Phase Crude Bunch Length
Bunch-Length Detector	BLD	2	Accurate Bunch Length

Table 1., Overview of the diagnostics

The layout of the diagnostics components in the HEL is generalized as follows. Each quadrupole magnet contains in its aperture a 9-cm long, 4-strip stripline beam position monitor (BPM). On top of each quad is an ion-chamber loss monitor (LM). There is one quad set per accelerating section—four per module. After the first and second sections of a module, there is a dipole trim (steering) magnet, capable of deflecting the beam by at least 2 milliradians. After the third section is a 3-wire slow-moving wire scanners (WS). After the last section is a vacuum valve and a multi-purpose resistive wall-current monitor (RWCM).

This paper details the operation of each of these in the Fermilab 400 MeV Linac. Particular attention is paid to how these devices were used during commissioning.

BEAM POSITION MONITORS

The BPMs used in the Linac are small, but otherwise, fairly conventional: 50 Ω, 4-plate striplines, 4 cm aperture, the plates subtend 20° [2]. The aperture of the quads has been made large enough to contain the BPMs.

The electrical centers of the BPMs is within about 100 μm of the mechanical center. Readout is through a AM-to-PM-based NIM module [3]. The least count on the ADC through the control system is about 15 μm.

An algorithm has been developed [4] to perform Linac steering. It measures the linear response of each BPM to a small change in each of the trim magnets upstream of the BPM and calculates the best values for the trim magnets to minimize the deviations in the beam positions. The nominal,

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well-steered beam positions are determined by finding the point in each quad/BPM which does not steer the beam when the quad gradient is changed. The algorithm works well.

During commissioning, the BPMs were called on to perform many other sorts of measurements. These measurements were: velocity, a backup longitudinal pickup for the phase-scan signature match and ΔT [5], and bunch length. The velocity measurements are discussed here.

Two velocity measurements have been performed. In one, the Linac beam pulse is made very short, a few beam bunches, and the lengths of the cables for two BPMs are adjusted, with jumpers and trombones, so that the signals overlap exactly. Then the time delay between the two cables is measured using a network analyzer. Knowing the separation of the two BPMs, the velocity of the beam is calculated. For example, the output energy of Tank 5 of the LEL has been measured to be 116.35 ± 0.51MeV. The second velocity measurement [6] calibrates the cables with a 201 MHz frequency generator in the tunnel (off-line!), exciting RF in one plate on each of the two BPMs, being careful that the phases are exactly equal at the BPMs. The opposite plate picks up a little RF energy, and so the phase difference between the two BPM signals in the equipment gallery can be measured. When beam drifts through these two BPMs, the measured phase difference, coupled with the separation, gives a velocity, modulo 2π. This method implies an energy out of Tank 5 of 115.6 MeV.

LOSS MONITORS

Our LMs read on a dimensionless scale of 0 to 100. It is thought that activity on a loss monitor is a very small number of lost particles. Losses observed in the Linac are generally below 10. If the losses in Module 1 exceed about 30, then it will spark, making further beam transport impossible. If the LMs in the 400 MeV exceed 50, then we see radiation in the equipment gallery adjacent to that region. If these losses persist, an interlocked radiation detector will inhibit further beam.

WIRE SCANNERS

The wire scanners have been used primarily to measure the transverse match between the LEL and the HEL. These wire scanners have three wires, measuring X and Y, of course, and the third one is at 45 degrees with respect to the other two, called U. These three wires overlap at a point near the outside of the beam aperture.

The wires are laid out in the HEL as described above. Additionally, an extra scanner is placed after the second section of Module 1, in place of a trim magnet. There are three scanners in the transition section. The three scanners are not positioned to give an unambiguous reading of the 116 MeV emittance, although a reading is possible. Combining in the two scanners in Module 1 give sufficient redundancy.

Several applications have been written to measure the emittances with these wire: A program to direct the wire scan, a program to edit bad points out of this measurement (a problem in the early stages of commissioning) and a general emittance calculation program using these data. Also, our colleagues from INR in Moscow contributed an off-line PC application to use all five wires to perform a best fit for the ellipse parameters. Once the calibrations on the scanners was correct, these programs agreed.

RESISTIVE WALL-CURRENT MONITORS

A RWCM is a gap in the beam pipe, lined with small resistors and tuned for maximum bandwidth. Inside the shield can is a ferrite ring, for measuring the low-frequency beam current. These combined-function devices perform three useful functions: 1., measure the beam current, 2., measure the phase of the beam (generally with respect to the reference line), and 3., measure the wall currents for a crude estimate of the bunch lengths.

Because this device contains a gap lined with resistors, and since it sits near a pulsed quadrupole, it is not possible to extract a perfectly clean beam current signal. The induced signal from the pulsing quad is approximately equal to the beam current signal. This is not an operational problem because the control system can subtract off the no-beam value and because the quad-induced signal will not change unless the gradient in the quad is changed.

It is possible to get a crude estimate on the length of the beam as it passes through a RWCM. The procedure, outlined in detail elsewhere [7], involves convolution of a gaussian beam profile with the expected response of the device, which is dominated by the beam-induced electromagnetic signals being spread out ahead and behind the beam with a characteristic angle proportional to $1/\gamma$.

Measurements made with the BLD are consistent with a RMS bunch length of about 25° throughout the Linac.

Using this device to measure the beam phase, it is possible to observe short-term and long-term drifts in the phase of the beam. In this Linac, the phase does not vary appreciably during the pulse or from pulse-to-pulse. In the monitor just upstream of the debuncher (45 m from the end of the Linac), we do see evidence that the phase is changing. The observation of this result during commissioning motivated us to change a faulty RF phase feedback card and to implement a gradient regulation loop in the HEL SCS cavities [1].

BUNCH-LENGTH DETECTORS

This device, known as the BLD, is described in detail in several references [*e. g.*, 8, 9]. It measures the average bunch length of a train of particle bunches over the course of the 30 second measurement time. This is accomplished by synchronizing the deflection of a secondary electron beam, created from the ion beam passing through a wire at high voltage, to the RF which bunches the beam. Adjusting the phase of this deflection allows density of different longitu-

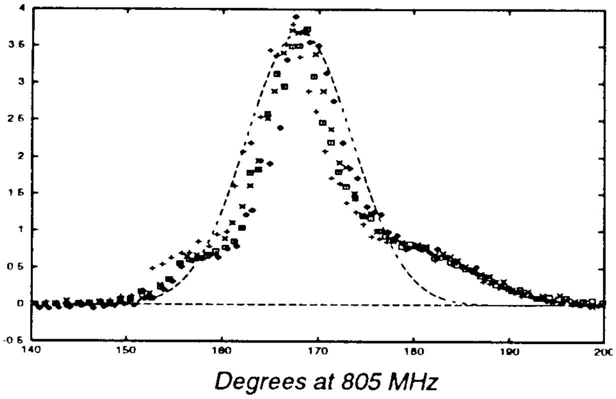

Figure 2., Four measurements of the Bunch Length at 116 MeV; Gaussian with σ=11°.

dinal slices of the beam to be measured.

Figure 2 shows a typical longitudinal distribution from the BLD 0.5 m upstream from Module 1 when the buncher in the transition section is tuned properly. Figure 3 shows the RMS width, as measured at this BLD, as a function of buncher gradient. The optimum focusing is at a gradient of 1 [10].

The BLD in the 400 MeV area, 0.4 m downstream of Module 7, has been used to analyze the longitudinal emittance of the Linac beam. Figure 4 shows the length at this BLD for different accelerating phases of Module 7, compared with simulation results for different longitudinal emittances.

A problem with the commissioning of these devices is that the deflecting cavity is necessarily synchronous to and resonant with the beam as it comes through the device. Since high voltage must be fed into the resonator [9], some of the RF energy from the beam can leak into the resonator through this path and excite the cavity. This reduced the effectiveness of the deflection at the phases near the peak of the beam signal. This problem was reduced by adding capacitive (low-pass) filters to the high-voltage feed points.

CONCLUSIONS

The beam diagnostics devices in the Fermilab 400 MeV Linac have been used during commissioning to measure and correct the beam parameters. Research into the character of the Linac beam is continuing.

ACKNOWLEDGMENTS

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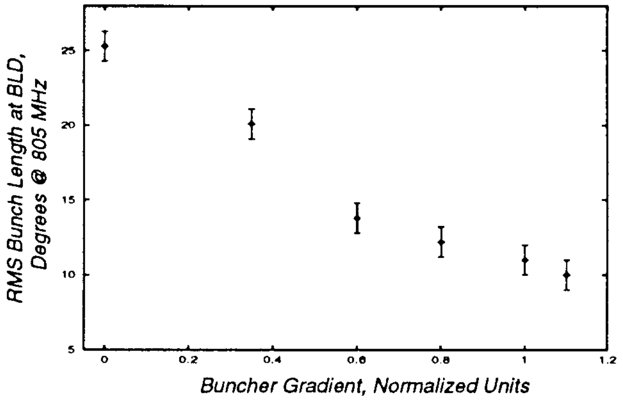

Figure 3., Tuning the high-energy buncher.

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[10] In fact, we normalize all gradient readouts to be 1.0 for the proper value of voltage in the cavity.

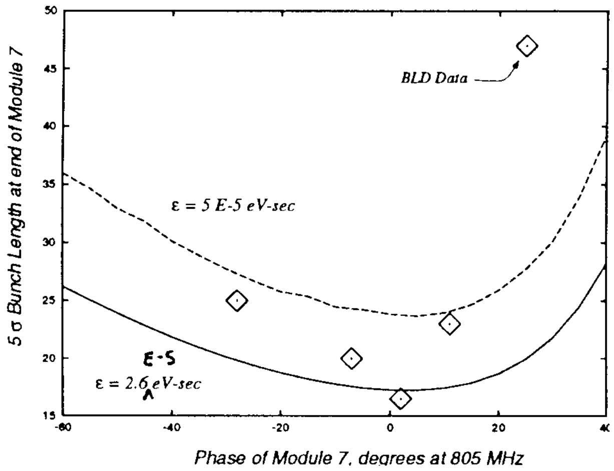

Figure 4., Longitudinal emittance out of the Linac using BLD measurements.