Abstract

Prototype beam diagnostics for the 400 MeV linac are being designed and tested. These new diagnostics include: wire scanners, stripline beam position monitors which fit within the quadrupoles, Tevatron-style resistive wall-current monitors and Feschenko-style bunch length detectors. Several of these devices have been tested with 116 MeV and 200 MeV H⁻ beam in the present 200 MeV linac.

I. INTRODUCTION

The last four 201 MHz Alvarez tanks of the twenty-year-old, 200 MeV Fermilab Linac are being replaced by seven high-gradient (7 KV/m), high-frequency (805 MHz) side-coupled-cavity structures to produce a 400 MeV beam for injection into the Booster[1]. Good, reliable beam diagnostics are an important factor in the success of this project, particularly for the commissioning. The diagnostics are being designed with the following challenges in mind.

✓ The space available for diagnostics is limited. There is only the four-meter transition section and 3/3m drifts between each accelerating section for the diagnostics.
✓ Good steering is important because the beam takes up a greater percentage of the aperture in the new Linac. In the new Linac, the beam aperture is smaller (3 cm vs the old 4 cm) and $\beta_{max}$ of the new beam is larger than in the old Linac.
✓ The longitudinal phase-space into which the beam is injected at the beginning of the new Linac is small. Therefore, measuring and understanding the longitudinal match between the two structures is important.
✓ Our old Linac, as reliable as it is, has yielded precious little information about the nature of its beam, especially in its middle where injection to the new linac is to occur. Thus, many plans and designs for the new Linac, the transition section in particular, rely on the existence of excellent diagnostics to identify and correct unexpected features of the beam revealed during commissioning.
✓ And, finally, we will need to commission the new Linac as quickly as possible, so it will be important to have reliable diagnostics as soon as commissioning begins.

We have made a design of each of the diagnostics elements. Figure 1 shows the mechanical layout of the inter-section regions for the second accelerating module.

II. DIAGNOSTICS SYSTEMS

A. Beam Position Monitors and Steering Correction

A quadrupole-stripline, non-intercepting beam position monitor (BPM) has been designed and prototyped. The four plates each subtend 20°. The inside diameter of the monitor is 3.25 cm., and the outside diameter is 3.8 cm — just enough to fit inside the pole-tips of the new quadrupole magnets. The overall length is 9 cm. The SMA vacuum feedthrough connectors on the strips are easily accessible between the poles of the quad.

Compact, picture-frame iron dipole magnets of the type used currently are to be used in the new Linac. We have made two types of these magnets: Type 1 is 6.5 cm long and has a total $|\mathbf{B}| dl$ equal to 3990 G-cm (at 5 A coil current); Type 2 is 9 cm long and has a total field of 5560 G-cm. The Type 1 magnets will go within modules 1 and 2, where space is most limited; the Type 2 magnets will go everywhere else, including the transition section [2]. With a Type 1 magnet at the beginning of module 1, a kick of 2.7 mrad is achieved.

There is to be a BPM within each quadrupole magnet, four per module, with instrumentation to read out four of the eight available signals from these monitors. This produces four position readings per $2\pi$ phase advance (79° per FODO cell),

Figure 1, Mechanical layout of the diagnostics within Module 2 of the new Fermilab 805 MHz Linac. The final drift shown here is repeated between sections 3 and 4.

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enough readings to accurately measure the steering and the betatron amplitude.

The rf signals from opposite plates of a BPM are converted to dc voltages proportional to the beam position and to the rf intensity by an RF module/decoder similar to the one presently in use [3]. The old design has been modified to increase the bandwidth of the position signal to 25 MHz (from 0.8 MHz).

A Linac control system local control station [4] will run a local application program to actively correct the steering of the Linac on a pulse-by-pulse basis.

B. Wire Scanners

A new, compact two-plane wire scanner has been designed. This stepping-motor-driven device fits in only 4 cm of beam line. Two wire scanners will be installed within module 1, one at a waist in X and the other at a waist in Y. A single wire scanner will be placed in each of the other modules.

A prototype has been installed at the output of Tank 5 in the existing Linac, the injection point of the new side-coupled Linac. Using the penultimate quadrupole magnet in Tank 5, we have measured the beam Twiss parameters with this wire scanner. The technique is the standard one, where the quad gradient is varied and the width of the beam is measured. The resulting curve in gradient-versus-width²-space traces out a parabola whose steepness is proportional to the beam emittance. The results are shown in Figure 2.

C. Bunch Length Detector (BLD)

A technique exists to accurately measure the phase extent (a.k.a. bunch length) and the phase density of a linac beam [5]. We have consulted with A. V. Feschenko and have built some prototypes. The details of the operation of this device can be found elsewhere.[6] Our goal is to obtain a resolution of approximately 1° at 805 MHz; Feschenko obtained a resolution of 0.8° at 198 MHz. Several small changes[6] in Feschenko's design are being implemented to obtain this increased resolution.

A rather high deflector gradient, around 2KV/cm, is required to achieve adequate resolution. A design for that deflector has been made using a pill-box cavity excited in a transverse mode. We will drive it with approximately 400 W of 805 MHz power with the same amplifier used for the driver stage of the klystrons.

We plan to install three BLD's in the transition section, two in the 400 MeV transfer line and one near the end of the linac, possibly within module 7.

D. Resistive Wall Monitors

Resistive Wall-current Monitors (RWM's) have been used with great success in the other accelerators at Fermilab.[7] A design has been made for the new Linac considering the smaller space (3 cm) and the smaller aperture (also 3 cm) of this accelerator. The RWM for Linac has a bandwidth of 6 GHz.

The RWM to be used in our new Linac will have triple duty. In addition to a rudimentary bunch length measurement

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\begin{align*}
\beta &= 3.9 \\
\alpha &= -0.8 \\
\chi^2/DOF &= 1.4
\end{align*}
\]

Figure 2, Emittance results using a single scanning wire and a tuned quad at 116 MeV in the existing Fermilab Linac.

(Their main function in the other Fermilab accelerators), extra ferrite has been added to facilitate a low-frequency beam current measurement. To save space, we have opted not to include Pearson-type beam toroids in our Linac in favor of this readout.

The third function performed by the RWM's is to provide a fast, beam-induced rf signal which will be used in the \(\Delta t\) procedure as the beam phase readout, see below.

A specially-modified Tevatron-style resistive wall monitor (aperture=8 cm, length=10 cm) has been installed at the output of Tank 5. The output of this detector has been analyzed. For a beam with velocity \(v<1\), the electric fields from a single particle in the center of the beam pipe spread by an angle which is proportional to \(1/v\). Thus, a delta-function beam does not produce a delta-function signal on a wall-current detector. (This, by the way, is the motivation for constructing a bunch length detector as described in the previous section.) Nevertheless, some bunch length information can be obtained from this device. One can compensate for this effect through a deconvolution of the observed signal from the spreading function.[6] The photograph, Figure 3a, is from the new Linac RWM at the output of Tank 5. Using this technique, we infer that this signal was produced from a beam with a phase extent of approximately 30° (±10°), Figure 3b.

E. The \(\Delta t\) procedure

A procedure has been established at several laboratories, most notably LAMPF, to accurately set the phase and gradient of a series of linac accelerating modules. This procedure, referred to as the "\(\Delta t\) procedure," is described elsewhere at this conference [9]. As stated above, it uses the fast, beam-induced rf signal from the RWM at the input to each module for the appropriate time-of-flight/phase information.

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Figure 3a. Signal from RWM at 116.4 MeV (1 GHz scope), observed FWHM = 440 psec.

Figure 3b. Results of convoluting beam signal with RWM response function. r=4 cm, E=116.4 MeV

F. Beam Loss Monitors

We will also include beam loss monitors in the new Linac. These devices have not been designed yet.

III. TRANSITION SECTION

The four-meter-long transition section matches the beam, transversely and longitudinally, from the 200 MHz drift-tube linac to the 805 MHz side-coupled cavity linac. Details on its design can be found elsewhere. Since most of the transition section is drift spaces for longitudinal and transverse matching, there is plenty of space for diagnostics.

Wire scanners are placed at the beginning, middle, and end of the transition section to facilitate emittance measurement. A simple way to measure emittance is to place the three wire scanners in a field-free region separated by drift spaces, as already implemented in the 200 MeV linac. For a more general case, this method requires knowledge of the transfer matrices through the space containing the three wire scanners. For this, we have used TRACE3D with the space charge effect included. (Including space charge makes the transfer matrix dependent on the beam profiles.) In particular, we studied the effects of measurement errors in the beam width, and of quadrupole reading errors on the resulting transverse emittance. For the transition section we have found that the sensitivity of the calculated transverse emittance on the measured beam width around its nominal value is higher in the vertical plane than in the horizontal plane. The functional form of the sensitivity curve is very close to linear with respect to beam widths at the beginning and end wire scanners, and close to quadratic at the middle wire scanner. Changes in the sensitivity due to space-charge effects are small. Errors due to both quadrupole regulation during the measurement and to reading errors are not significant for the first and last quad, but a 1% error in the second quad makes a 2% error in the emittance.

We plan to include three bunch length detectors in the transition section to allow us to measure the longitudinal emittance of the beam. This method is essentially similar to the transverse emittance measurement just described. Because of the tight space between Tank 5 and the debuncher cavity, the latter had to be moved downward by 10 cm to accommodate a wire scanner, a steering coil and bunch length detector. Calculations made with TRACE3D have shown that moving the debuncher in this manner without a significant change in its field gradient, still gives an acceptable longitudinal beam profile.

IV. CONCLUSIONS

In order to commission the new 805 MHz/400 MeV Fermilab Linac in the allotted time, extensive and accurate beam diagnostics are to be used. In addition to fairly standard beam position monitoring and correcting, we plan to include in the new Linac: wire scanners for emittance measurement, at pickups to aid in setting the phase and gradient of the high-power klystrons, and bunch length monitoring devices throughout the Linac.

IV. REFERENCES

[2] Terminology: sixteen side-coupled cavities are braised together to make a section, four sections are connected together to make a module, a module is powered by a klystron.