THE BEAM PROFILE MEASUREMENT SYSTEM AT THE BATES LINAC*

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Abstract

A linac beam profile measurement system using wire scanners has been implemented at the Bates Linear Accelerator Center. This facilitates obtaining an optimum linac focussing solution. A nearly non-invasive beam size measurement is made of the two beams which are accelerated simultaneously in the recirculating linac. The wire scanner mechanical accuracy is near one mil. Beam size measurements are reproducible to a few mils.

Introduction

Convenient operational procedures for measuring beam optics are important in order to optimize accelerator performance and efficiency. In some cases it is necessary to measure the optical matrix elements in order to achieve the desired beam optics. This can be done, for example, in single pass beam transport systems where the first order optics may be crucial to its performance. Sometimes it is sufficient to ensure good beam transmission. For example in a linac, the beta functions (beam size) could be measured. Direct beam profile measurements are convenient and yield useful information.

The MIT Bates Linac accelerates a high quality electron beam with energy up to 1 GeV and a duty factor of up to 1%. This high quality beam is characterized by low emittance ($10\pi/\gamma$)mm-mr and small energy spread (0.3%)[1]. Energies above 500 MeV are achieved by recirculating the beam through the linac.[2]

A consequence of the low emittance is that weak focussing is generally used in the single pass beam operation. Also, there are a fairly wide range of acceptable focussing solutions. In particular there are only 6 quadrupole doublets used for accelerator focussing in the 200 m long, 22 section machine. A computer simulation of a typical weak focussing solution beam envelope is shown in Figure 1. The focal length of the doublets range from a few meters to 50 meters. There is barely 180 degrees of betatron phase advance through the accelerator.

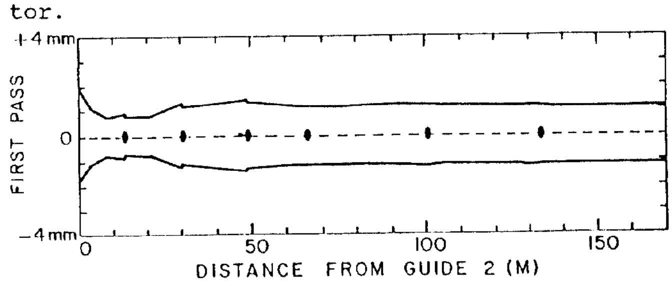

Fig. 1: Computer Simulation of beam envelope using a "weak focussing" solution. Ellipses on axis represent location of quadrupole doublets.

Focussing two beams of different energy is more difficult. The focussing strength must be stronger to transmit the second pass beam through the accelerator through apertures as small as 12 mm. However, that strength must not be too excessive for the lower energy first pass beam. At the reinjection point the first pass beam energy is 20 MeV, while the second pass beam energy might be as high as 520 MeV. The second pass beam results in a second period of beam loading transient (2.3 MeV/mA) which must be transmitted through the recirculation system, including the accelerator, before a steady state is established. This requires a large energy band pass system. The system has an energy bandwidth of over 5%. This depends upon a focussing scheme which is used to aid transmission of "off energy" transient electrons. A computer simulation of the beam profile for this scheme is shown in Figure 2.

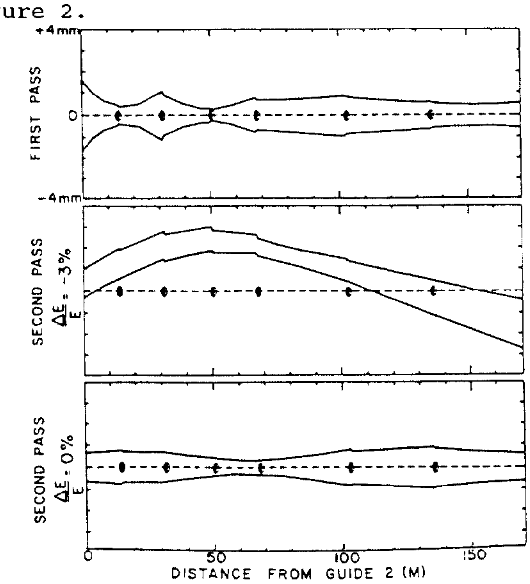

Fig. 2: Computer Simulation of beam envelope using the strong focussing solution for optimizing the energy band pass. The upper trace represents the first pass beam envelope. The lower traces represent the second pass on-energy beam and a beam off-energy by 3%.

It is important to provide an operational procedure for the determination of the focussing solution. We have done so by implementing a system of wire scanners for the purpose of measuring the electron beam profile in the linac. This system is interfaced with a computer control system which allows displays for use by the accelerator operators.

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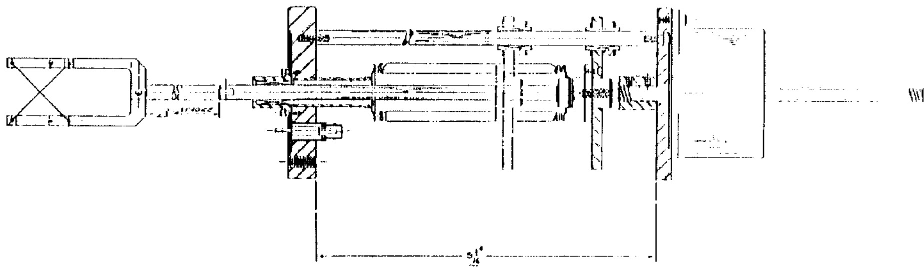

Fig. 3: Wire Scanner Schematic

Wire Scanner

The wire scanner design is shown schematically in Figure 3. Each scanner consists of a horizontal and vertical 20 μm wire driven across the beam by a stepper motor. At maximum speed, the 7.6cm stroke can be completed in approximately 10 seconds. The stepper motor is triggered by the beam pulse so that the actual scanning rate depends upon the beam repetition frequency. The system is capable of steps as fine as 0.5 mils at a speed of close to 1 kHz.

The beam profile is determined by measuring the secondary emission from the wire as a function of wire position. The position is determined by counting the steps of the stepping motor and recalibrating periodically. The signal is amplified by an amplifier developed in house capable of selectable gains from 0.1 mV/nA to 10 mV/nA. The amplified signal is digitized and acquired by a microcomputer for broadcasting over the Linac Control System local area network.[3]

Wire scanner bench tests show a wire position reproducibility of 1 mil. In-beam measurements were made of the combined effects of wire scanner reproducibility, wire stiffness and beam stability. The beam stability contribution will arise from beam fluctuations on a time scale longer than the time for a scan (several seconds). Figure 4 shows the signal from a scanner installed in the beam line. The signal is accumulated over many scans and plotted. The thickness of the profile outline is a measure of the above effects. In Figure 4 this thickness is about 10 mils. However, the beam width measurement reproducibility is much better.

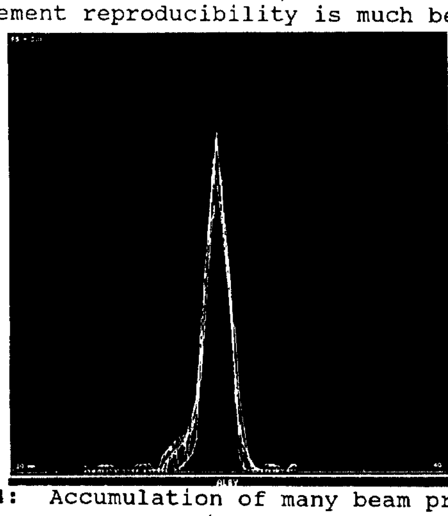

Fig. 4: Accumulation of many beam profile measurements.

Implementation

The wire scanners are placed in the accelerator to optimize the data obtained with the existing focussing system. They are installed at the location of the quadrupole doublets to enable measurements of the beam profile where the beam is largest and where limiting aperture collimators exist. They are also installed between these locations in order to determine the beam profiles near the beam minima when using a strong focussing solution for the first pass beam. Since the second pass beam is more weakly focussed, this system will overdetermine the second pass beam mimima and maxima. An important and immediate benefit of this system is the simultaneous measurement of the first and second pass beam profiles as shown in Figure 5. Not only are the two beam sizes measured but the relative beam positions are also displayed. This enables the steering and optics of the recirculation system to be set correctly in real time.

For measurements of the single pass beam other display options are available. Figure 6 shows a horizontal beam envelope display derived from the full width half maxima of the beam profile plots. This weak focussing scheme can be compared with the simulation profile shown in Figure 1. Aperture information can be simultaneously displayed in the beam cross section plot shown in Figure 7.

Further applications of the wire scanner system in the beam switchyard include beam phase space measurements discussed elsewhere in this conference.[4]

Conclusions

It is important to provide a real time method for beam tuning and diagnostics. For this it is best to use nearly non-invasive techniques with a response time on the order of seconds or less. While information for setting transport line optics can be obtained, we have found beam profile measurements in the linac to be very useful. This is especially true when using recirculation techniques and more than one beam exists in the accelerator. Displaying that data in a form useful for physical comparisons with apertures, or comparisons with beam simulation output is also important.

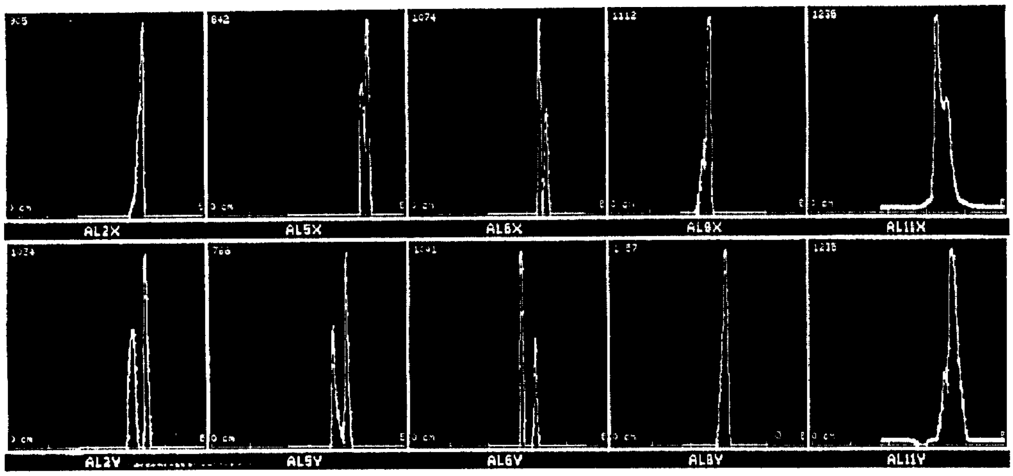

Fig. 5: Beam profile measurement with two beams in the accelerator. The top row shows horizontal profiles, and the bottom row shows vertical profiles, at different locations in the accelerator.

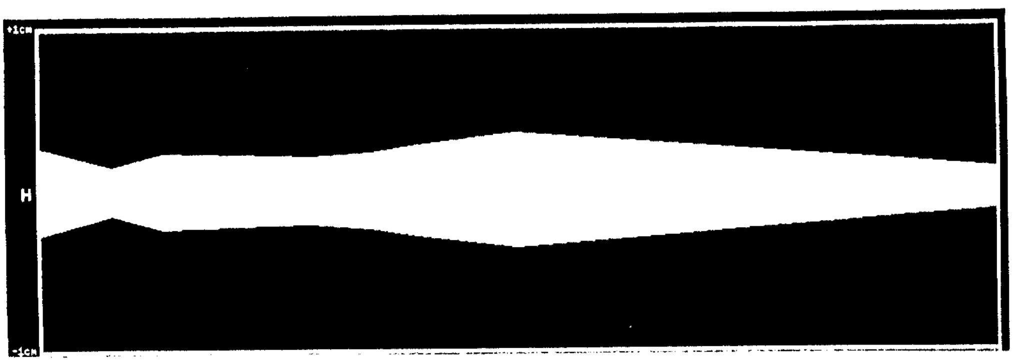

Fig. 6: Measured Horizontal beam envelope in the accelerators.

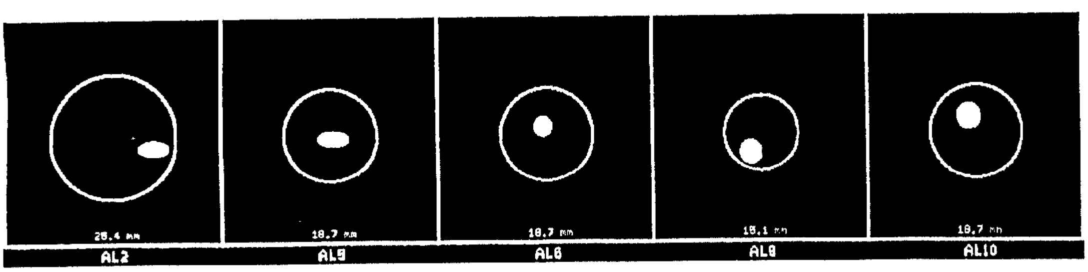

Fig. 7: Horizontal and vertical beam profile information compared with acccelerator apertures at different locations in the accelerator.

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