An Electrostatic Sweep Plate Device for Emittance Measurement of Ion Beams to 2 MeV*

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Abstract

Electrostatic sweep plate devices have been used previously for the measurement of ion beam emittance.[1] These devices may be routinely designed with an ultimate angle resolution of ±0.25 mrad or less. We have used a similar device for measuring the emittance of H^- and H^+ beams exiting an RFQ at 1 MeV. This scanner will be used to characterize the beam exiting a low-power DTL at energies up to 2 MeV. The physics design changes consist primarily of increasing the length of the deflection plates and decreasing their separation to obtain high electric field at low deflection plate voltage. The front face of the scanner was made thicker and designed for water cooling to withstand the beam power at up to 2 MeV. In this paper the design of the scanner is discussed. This includes the device angular resolution and maximum acceptable angle. The thermal analysis that led to the design of the water-cooled front face is shown. Data showing the performance of the device and resulting emittance measurements at 1 MeV are presented.

I. INTRODUCTION

For many accelerator applications, the most important parameter is the ion beam's transverse emittance. The device of choice for the highest precision emittance measurement is an electrostatic sweep plate scanner[1]. We have been using such a device for H^- and H^+ beam emittance measurements at energies between 10 keV and 35 keV[2] on our ion source test stand and accelerator beamline.

We have installed an RFQ on our beamline and plan to install a matching section and DTL at the end of the RFQ. To characterize the beam at the output of the RFQ (1 MeV) and at the output of the DTL (1.76 MeV), the sweep plate scanner was redesigned. The design goal was to obtain a maximum sweep plate voltage of 2.5 kV while keeping the length of the deflection plates to a reasonable length. In addition the front face of the scanner was designed to withstand the 30- to 60-fold increase in beam power at the higher beam energies.

In the original design[2], the scanner was mounted on a ring that rotated through 90°. This permitted the measurement of emittance in both the horizontal and vertical beam directions using a single device. This ring assembly was made more rugged for the larger and heavier scanner. Figure 1 shows the side and front views of the new scanner mounted in the more rugged ring assembly. In this figure, the scanner is positioned for use in the horizontal direction. The scanner is guided on a lead screw that is driven by a pulley attached to a stepper motor.

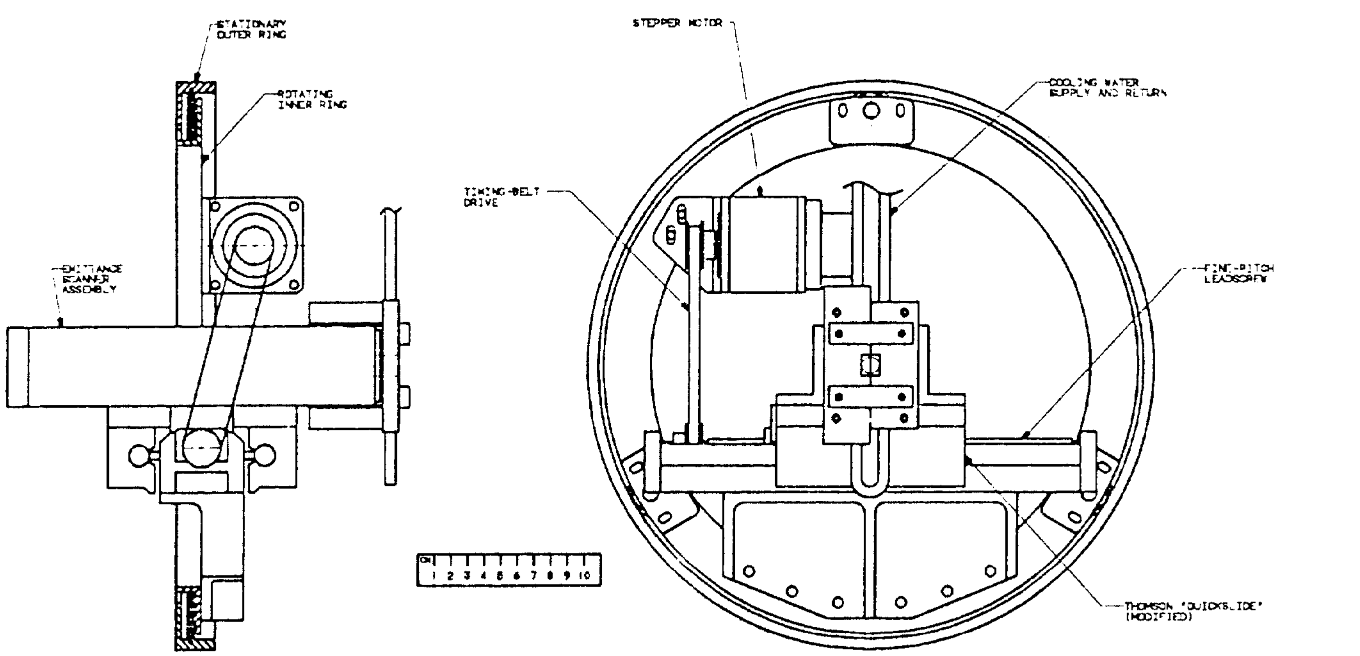

Figure 1. Front and side views of the ring assembly for the high-energy emittance scanner.

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II. PHYSICS DESIGN

Since the energy of the beam downstream of the RFQ is two orders of magnitude higher than in the LEBT, the scanner deflection plates were made longer and their separation was made shorter. Fortunately, the beam divergence at the RFQ output is expected to be less than 45 mrad, compared with up to 130 mrad at the source output.

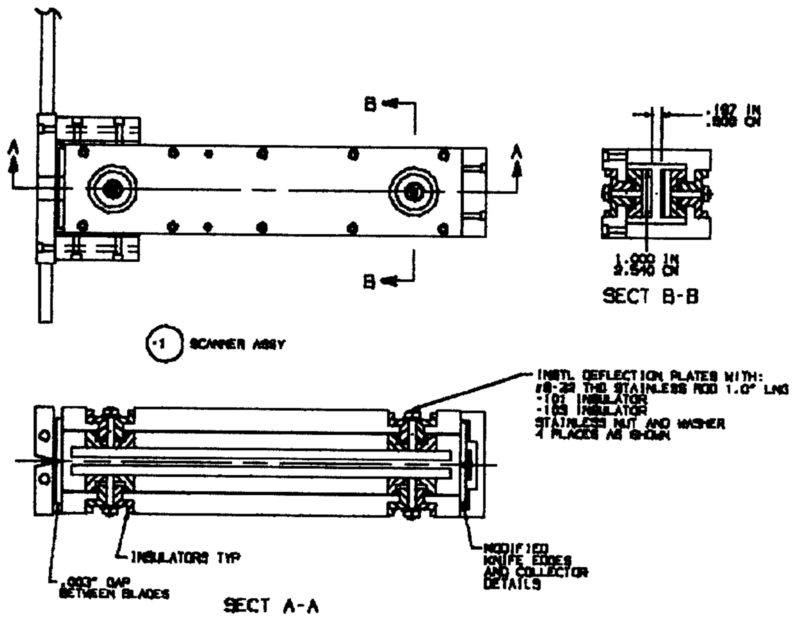

Figure 2. Top, side, and front views of the high-energy emittance scanner.

Figure 2 shows a three-view schematic diagram of the new scanner and Table 1 shows the critical dimensions of both the low- and high-energy scanners. The resulting relationship of deflection plate voltage vs. beam angle for the redesigned scanner is shown in Figure 3. Note that the maximum voltage that need be applied to the high-energy scanner is 2300 volts, compared with 123 volts for the low-energy scanner. The angle resolution for both scanners is shown. This was obtained by calculating the angular range of ions that would pass through the top and bottom extremes of the entrance and exit slits at constant deflection plate potential. This becomes ±0.62 and ±0.38 mrad for the low- and high-energy scanners respectively.

Table 1
Comparison of Parameters for the Low- and High-Energy Emittance Scanners

	Low Energy Scanner	High Energy Scanner
Defl. Plate Separation (cm)	0.132	0.5
Defl. Plate Length (cm)	3.8	20
Field-Free Regions (cm)	0.16	0.5
Slit Opening (cm)	0.0025	0.0076
Nominal H^- Energy (keV)	30	1013
Max. Analyzable Angle (mrad)	±59	±45
Max. Defl. Plate Voltage (V)	±123	±2300
Angle Resolution (mrad)	±0.62	±0.38

III. THERMAL DESIGN

A thermal/structural evaluation was performed to support the design of the high-energy scanner. The purpose of the study was to determine the maximum temperature of the protective front face and to determine the extent of the deformations of the knife blade assemblies during beam impact using various amounts of water cooling. The beam parameters used were 30 mA at 1% duty factor, 10 pulses per second (1ms pulse length). The analysis was performed using the finite element code, ANSYS. The resulting temperature distributions of the front face and knife blade are shown in Figure 4 assuming a water flow of 1.5 - 2.0 GPM. With these temperature distributions, the thermal stress due to temperature cycling of the molybdenum should not produce fatigue cracking.

Another thermal consideration was the vertical deflection of the knife blades due to beam heating. The analysis showed that, in the worst case, each knife blade should deflect (toward closing the slit opening) by 0.55 mils; therefore, a slit opening of 3 mils was chosen to permit a minimum slit opening of 1.9 mils.

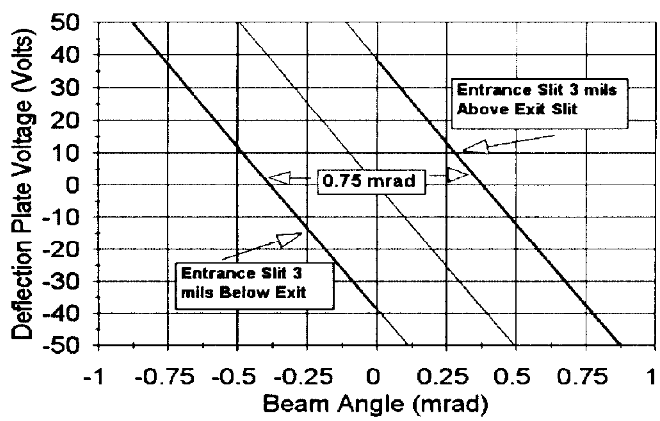

Figure 3. Voltage on each deflection plate (opposite polarity) as a function of beam angle. The angular resolution is the range of angles transported through the entrance and exit slits at constant deflection plate voltage.

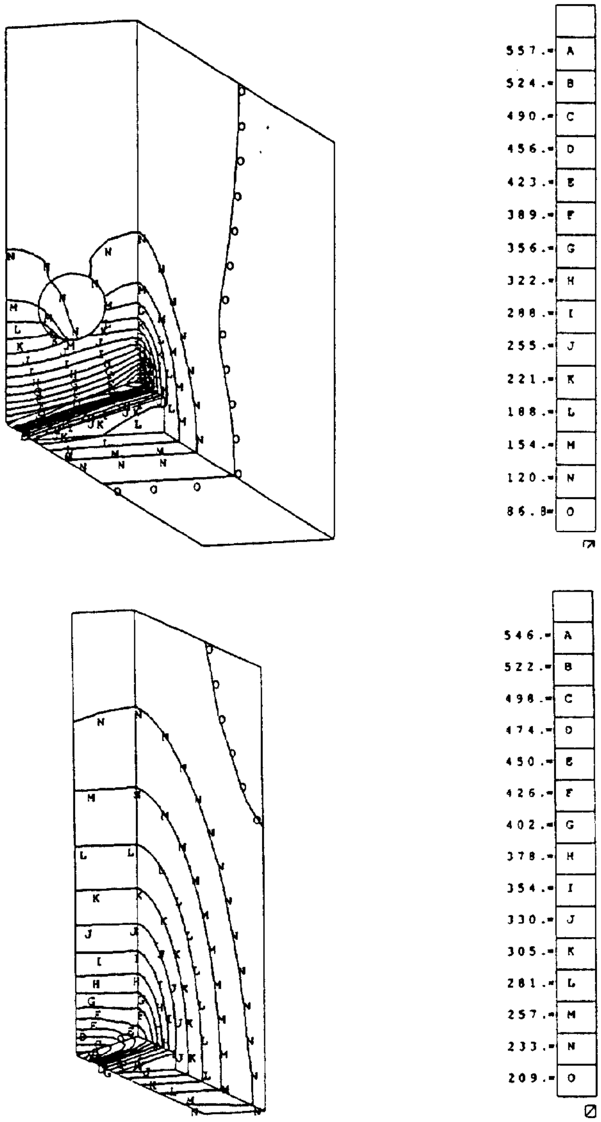

Figure 4. Thermal contours on the protective front face (top) and slit knife edge (bottom) for a 30 mA, 1% duty factor beam

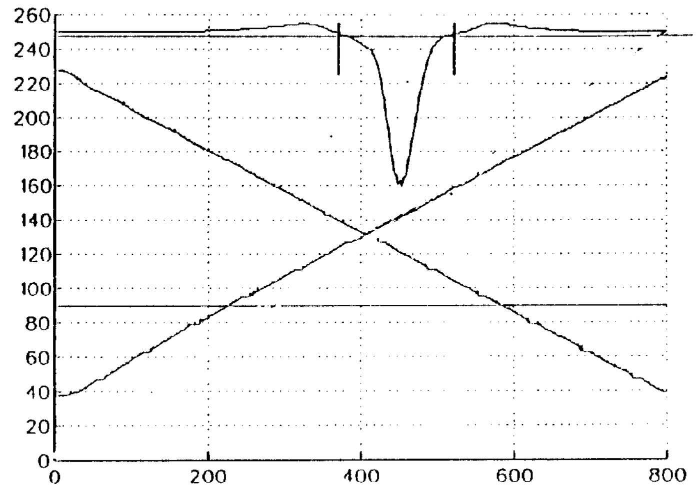

Figure 5. Typical digitized beam single-pulse signals. The crossing lines show the relative potential on each deflection plate.

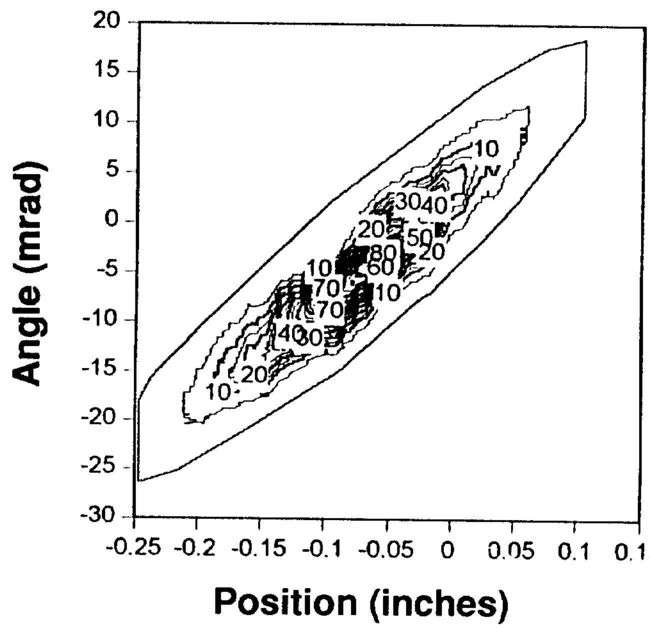

Figure 6. Typical phase-space contour plot obtained for the 1-MeV beam exiting the RFQ.

IV. DEVICE PERFORMANCE

Figure 5 shows a typical digitized signal obtained at a single position for the high-energy scanner at the nominal values shown in Table 1. Also shown is the relative voltage of each deflection plate during the beam pulse. A computer program is used to translate the amplitude of the signal at each value of deflection plate voltage into the relative current at each beam angle in the beamlet. After obtaining digitized signals at a series of positions in the beam pulse, a contour plot of the relative beam intensity at each position and angle is obtained. This plot is shown in figure 6. This phase space plot corresponds to a normalized rms emittances of 0.007 π cm mrad for the high-energy beam.

V. REFERENCES

[1] Paul W. Allison, Joseph D. Sherman, and David B. Holtkamp, "An Emittance Scanner for Intense Low-Energy Ion Beams," *IEEE Trans. Nucl. Sci.* **NS-30**, No. 4, 2204 (1983)

[2] R. Heuer, K. Saadatmand, L. Solensten, T. Debiak, J. Sredniawski, and F. Kuehne, "A New Stand-Alone Beam Emittance Measurement System," *Nucl. Instr. and Meth.* **B56/57**, 1148 (1989)