AN EMITTANCE MEASURING UNIT FOR 100% DUTY FACTOR LINAC INJECTOR BEAMS

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Summary

This paper describes a system to measure the emittance of a 750 keV 100 mA dc proton beam suitable for injection into a 100% duty factor linear accelerator. A relatively slowly pulsed 45° magnet switches the beam to a beam dump inside the emittance measuring unit for ∿ 10 s. A fast pulsed 5° magnet then deflects the beam to a multiple aperture "pepper-pot" plate for 300 μs. Beamlets passing through the plate travel 520 mm and produce a pattern on a scintillator screen. A photograph of the pattern is analyzed to determine beam emittance. Preliminary results on low current beams show a gross increase in the emittance in the horizontal plane.

Introduction

The Chalk River High Current Test Facility[1] is a 100% duty factor proton accelerator consisting of a 750 keV injector[2], beam transport system, buncher and a cw Alvarez structure designed to accelerate up to 100 mA to 3 MeV. This facility is being built to investigate the problems associated with the acceleration of high current continuous proton beams. Space charge effects can cause a large increase in the beam emittance especially at low energy; therefore an emittance measuring unit is an important diagnostic device.

Figure 1 shows the layout of the beam line for the High Current Test Facility injector. When the linac is not operating the beam travels straight through the first bending magnet into the dump. For an emittance measurement the beam is deflected into the emittance measuring unit by pulsing the first 45° bending magnet, with the second 45° magnet switched off.

The Emittance Measuring Unit

The emittance measuring unit (Figure 2) consists of a fast 5° deflector magnet, a pepper-pot aperture plate and a water-cooled beam dump. The beam is held in the dump until its position is stable (∿ 5 s). Then the 5° magnet deflects it onto the pepper-pot plate for 300 μs. The time is kept short to protect the pepper-pot plate, since the beam power may reach 75 kW. The beamlets passing through the pepper-pot plate strike a scintillator screen where they produce a visible pattern. The pattern on the screen is then photographed for analysis.

The 5° magnet (Figure 3) is a 206 mm long picture frame type having a lithium zinc ferrite frame, with a gap of 50 mm and an internal width of 183 mm. It is excited by a four-turn copper strip winding. Magnetic field measurements give an effective length of 237.5 mm, thus 0.046 T is required to bend a 750 keV proton beam.

[a] Now with Ontario Hydro, NPD, Rolphton, Ontario.

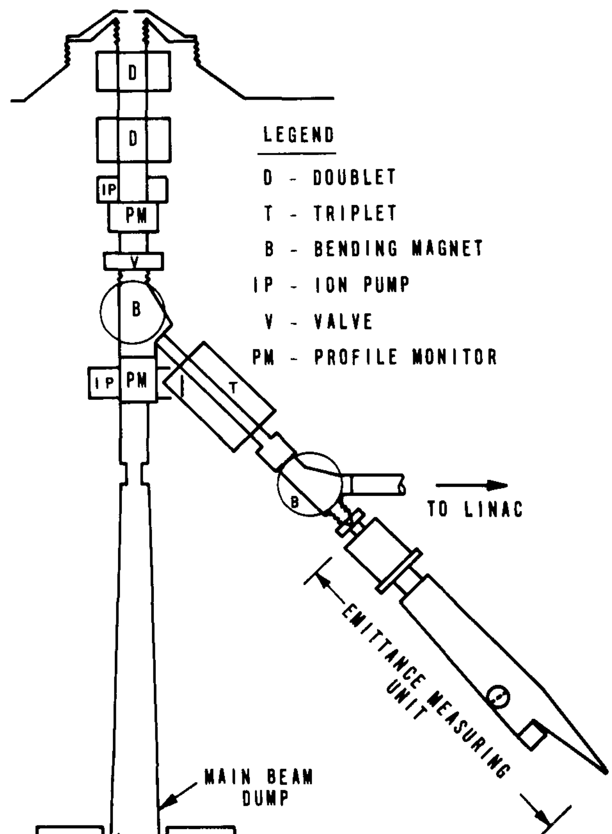

Figure 1. Layout of injector beam line.

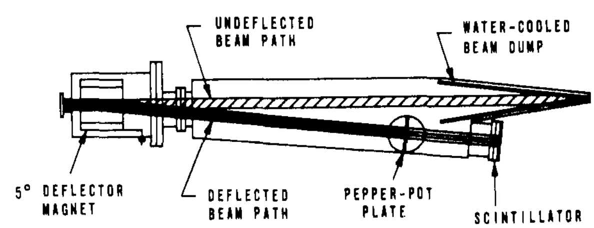

Figure 2. Layout of emittance measuring unit.

The magnet pulser circuit[3], shown in Figure 4, uses a 1 ohm lumped-constant delay line as a pulse forming network. The line is graded to minimize pulse droop. A "tail biter" circuit is used to decrease the pulse fall time. The pulse forming network and tail biter capacitor are charged to approximately the same voltage with polarity as indicated. The current through the magnet winding is switched on by SCR switch S1. After 300 μs,

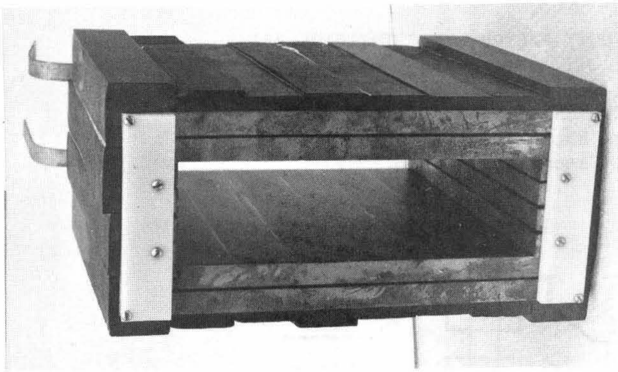

Figure 3. Fast deflector magnet.

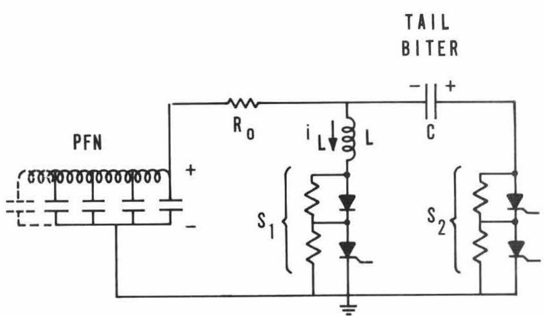

Figure 4. Pulser circuit.

SCR switch S2 is switched on, diverting the current from the magnet winding into the tail biter capacitor, switching off S1 and rapidly cutting off the magnet current. There is less than 1% rise in the current during the pulse and current ripple is less than 0.25%. The duration of beam motion across the pepper-pot plate is short enough compared to the flat-top portion of the pulse that there should be no noticeable blurring of the photographic image for exposures that do not overexpose the main pattern.

Figure 5 is a sketch of the pepper-pot plate which is located 1.5 metres beyond the 5° deflector magnet. There are 15 holes vertically and 25 horizontally spaced 5.08 mm apart. The insert in the figure shows the details of the individual holes. The hole diameter of 0.127 mm was chosen to comply with the criteria of Evans and Warner[4]. The aperture plate is mounted on a heavy copper plate which is then fastened to a large flange with boron nitride electrical insulators. These insulators of good thermal conductivity provide good cooling while allowing a bias voltage to be applied to the aperture plate. The bias voltage is required to prevent secondary electron emission from the plate. The beam current pulse to the pepper-pot plate is determined by measuring the voltage drop across a 1 kΩ resistor between the plate and ground. The detector screen, visible through a glass window, is a thin sheet of NE 102 scintillator material placed 520 mm downstream from the pepper-pot plate. This spacing gives an angular resolution of 0.2 mrad.

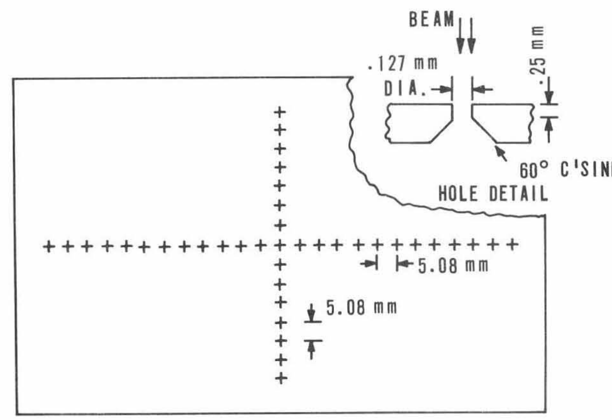

Figure 5. Pepper-pot plate.

The beam dump consists of two 6 mm thick copper plates in an 18° "V" with the open end toward the beam. The plates are water-cooled but we rely on their thermal capacity to absorb the beam energy. During the slow pulse, the copper temperature rises ∿ 200°C at 100 mA beam current.

Preliminary Emittance Measurements

Emittance measurements have been made at proton currents of 5 and 10 mA at 650 keV. Only the 10 mA measurements will be reported as the major features are the same in both cases.

Figure 6 shows the current pulse to the plate. The combined rise and fall time is less than 5% of the total pulse length. There is about 4% modulation of the beam current. The plate self bias produced across the 1 kΩ resistor is sufficient to prevent any significant secondary electron emission. No change in the beamlet pattern or in the measured current pulse shape or size was found for up to 180 V additional bias.

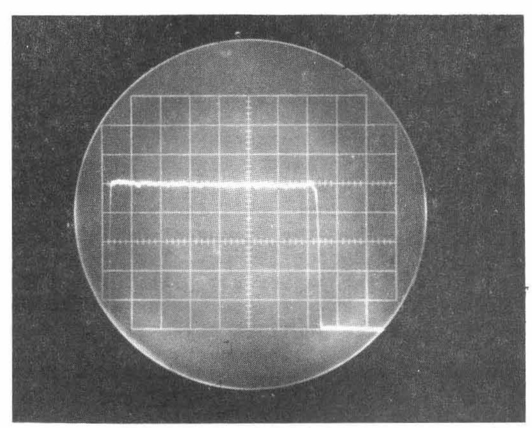

Figure 6. Beam current pulse to pepper-pot plate.

Figure 7 is a composite photograph of the beamlet pattern made by taking separate photographs for two different beam deflection angles. The divergence in the horizontal plane was so great that the full pattern could not be displayed on one photograph; indeed the "tails" extended past the edge of the second photograph. A third photograph was not possible as the main portion of the beam (shown by the relatively circular dots) struck the chamber wall and the electrons generated caused the scintillator screen to flare. The tails are not caused by the beam sweeping across the plate and are generated by some mechanism upstream from the second bending magnet because -

1) For some settings of the triplet quadrupole lens just before the emittance unit (Fig. 1), the tails are nearly vertical, are separated from the dots or start "ahead" of the dots.

2) There are tails without dots.

3) Measurements made with thermocouple probes upstream of the second bending magnet show that the boundary on one side of the beam (the side corresponding to the dots) is sharply defined; the boundary on the other side is diffuse.

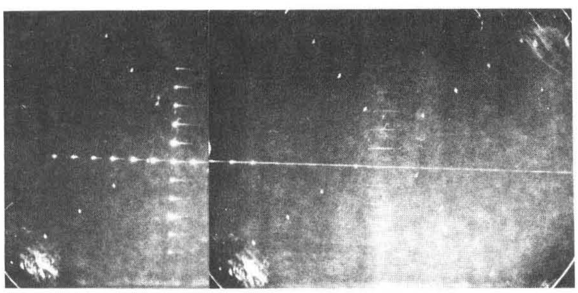

Figure 7. Beamlet pattern

By comparing the currents to the plate when the beam was shifted so that a minimum and maximum amount of the tails struck the plate it was determined that more than 10% of the total beam current was in these tails. Figure 8 shows the emittance plot for the horizontal plane showing the phase space areas for the dots (80-90%) and for the tails (10-20%) of the beam. The normalized emittance in the horizontal plane for the major part (80-90%) of the beam is 1.8 π mm mrad. The value including tails is greater than 15 π mm mrad; because measurements could not be made to the edge of the beam, and because the tails overlapped over most of the range, this figure must be considered as a lower bound for the true value. The measured emittance in the vertical plane is 1.5 π mm mrad. All of these are much worse than the normalized emittance of 0.48 π mm mrad measured for the same ion source under the same operating conditions on a 60 kV test stand.

Discussion

The emittance measuring unit has an angular resolution of better than 0.2 mrad. This gives a minimum resolvable normalized emittance of 0.01 x (number of holes illuminated) π mm mrad. For (typically) 15 holes illuminated, this is 0.15 π mm mrad. Reproducibility is excellent and there is no observable effect from the beam sweeping across the pepper-pot plate. An increase in beam current is

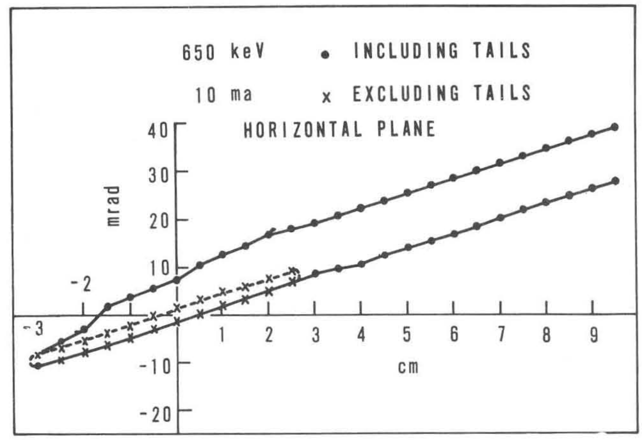

Figure 8. Emittance plot for horizontal plane.

not expected to degrade this performance. Neither the beam dump nor the aperture plate showed any damage at the beam intensity encountered in preliminary measurements. The large increase in beam emittance in the horizontal plane is not yet understood.

Acknowledgements

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