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MEASURING BEAM EMITTANCE FOR HIGH-ENERGY H^- ACCELERATORS*

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Summary

A novel technique is presented for measuring the six-dimensional beam emittance for high-energy H^- accelerators in real time. This techniuqe uses the single charge exchange cross section from thin and narrow foils (intercepting 1-3% of the beam) as a line source for measuring the divergence and momentum spectra for operating H^- accelerator beams. By scanning the foil across the beam, X, Θ, and p beam density spectra and emittance can be determined. The introduction of a second foil provides the Y-ϕ emittance. Operational experience of this low cost emittance measuring device has been obtained from the 50-MeV H^- linear accelerator at Argonne National Laboratory, simultaneously with its use as an injector into the Rapid Cycling Synchrotron (RCS).

Introduction

Real-time diagnostic beam emittance information from operating high-energy accelerators has been difficult to obtain in the past. The information obtained from such instrumentation would be of great value for both tuning and operating the accelerator. With the increased sophistication of modern accelerator systems, real-time beam emittance information has become essential for maximizing the overall accelerator efficiency. The recent change to H^- ions in the injection accelerator makes possible an entirely new type of low cost, direct measurement devices to determine the beam emittance.

This paper will describe a novel method for measuring the emittance of operating H^- accelerators in real time. The instrumentation required is simple in concept, low in cost, and provides a direct measurement of the five-dimensional beam phase space. The concept developed here can be modified to also provide a measurement of the time or phase dimension.

The principle behind this technique is the use of a thin foil to probe a small sample of the incident H^- beam, permitting normal operation to continue essentially unaffected. A fraction of the H^- ions undergo a single charge exchange and pass through the foil with negligible effect on the divergence angle or momentum of the ion. Charge separation of H^- from H^0 is easily achieved using existing beam transport magnets and the divergence of the H^0 beam can be measured with multiwire chambers. Scanning of the foil through the beam will yield the density spectra in the X-Θ phase space. A second foil orthogonal to the first then yields the Y-ϕ phase space density. Finally, the density in momentum phase space can be determined by a simple spectrometer after the H^0 beam undergoes a final charge exchange ($H^0 \rightarrow H^+$) in another thin foil. With sufficient drift distance for the H^0 beam, a high momentum resolution is possible with a low cost spectrometer magnet and multiwire chamber to measure the dispersion. All of these measurements are shown to be possible while reducing the initial beam intensity by the order of only 1%.

Beam Design and Operation

Figure 1 shows a schematic layout of the diagnostic beam built to demonstrate this technique. This beam made use of an existing transport line to the ZGS in order to reduce costs. This layout was not ideal because of the background H^0 from gas stripping in the linear accelerator. However, the existing physical arrangement precluded placing the stripping foil after the bending magnet, which would have virtually eliminated this background. In addition, the signal of H^0 from the stripping foil was expected to be large enough to permit a background subtraction technique to be used in this experiment.

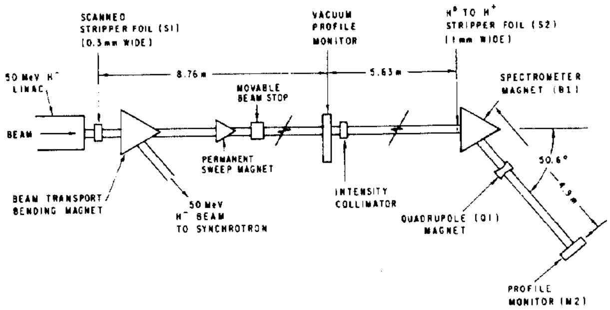

Fig. 1. Schematic Layout of the 50-MeV Linac Diagnostic Beam Used to Measure the Emittance of the 50-MeV H^- Accelerator Beam

The scanned foil was approximately 0.3 mm in width and intercepted less than 3% of the H^- beam from the linear accelerator. For the most successful foils, about 10% of the beam incident on the foil was converted to H^0 and the remaining 90% to H^+. The H^+ ions created an increased radiation background after charge separation in the transport magnet to the RCS. To help reduce the H^0 background from gas stripping, a cleanup foil was placed after this magnet to change its charge. A small, permanent dipole magnet (0.36 kG-m) was used to sweep out the resulting charged particles. This sweeping magnet also served as a radiation protection device, preventing the intense H^- beam from passing through the beam line if the transport magnet failed.

After almost 9 m of drift space, the angular divergence of the H^0 beam was measured with a multiwire ionization chamber. The beam signal was determined by subtracting the foil-out signal (background H^0) from the foil-in signal. The ratio of the beam signal to background varied from 1.5 to 3.5, depending on the foil used. The foil was capable of being scanned through the 1.5 cm wide beam in about 20 seconds, yielding the two-dimensional emittance plot shown in Fig. 2.

With the profile monitor pulled out of the beam, the H^0 beam drifted an additional 5.6 m to a second stripping foil (1 mm wide). This foil converted a fraction of the H^0 beam to H^+ and defined the incident

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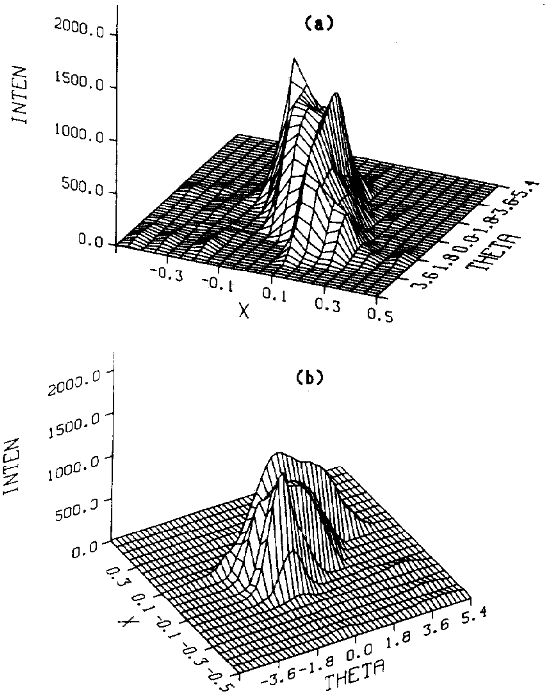

Fig. 2. Density Spectra of the 50-MeV H⁻ Beam for the Horizontal Position (X in inches) versus the Horizontal Divergence (theta in milliradians)

angle into the momentum spectrometer to ±0.05 mrad. A second profile monitor (multiwire proportional chamber) measures the H^+ momentum spectra with a fractional error of $\pm 2 \times 10^{-4}$ ($\Delta P/P$). The initial design of this beam called for a scintillation counter hodoscope to measure the angular divergence of the H^o beam. With the scintillation counters split in the midplane, simultaneous measurements of divergence and momentum spectra would have been possible.

The use of H^o to define the incident beam has a significant advantage in reducing background in the momentum spectrum due to slit scatter in the collimators and residual gas. This would have required an additional sweeping magnet after the collimator, but this was not done due to the already large H^o background from gas stripping in the linear accelerator.

Foil Construction

The most challenging part of this beam was the construction of foils to provide the H^o source. The foil thickness is quite critical, since a too-thick foil yields a small H^o signal and mostly H^+ ions, which cause increased radiation to men and equipment. Figure 3 shows the dependence of the fraction of charge states produced as a function of foil thickness, based on charge exchange cross sections at lower energies.[1] The ideal thickness is seen to be about 300-500 Å at 50-MeV. In addition, the foil must be supported and must maintain its width while being scanned through the intense H^- beam.

The foils used here were made of Parylene[2] with thickness ranging from 600-1700 Å. The foil was vacuum deposited on a glass substrate and floated off with water. To maintain the width and support this foil, two 10 μm glass fibers were mounted 0.3 mm apart on the foil support frame, and the foil layed across these fibers. The excess foil was trimmed by using a laser or hot-wire. The unirradiated foils showed little or no tendency to contract. After exposure to the beam, the foils tended to contract to less than 0.1 mm width, reducing the available beam signal by a factor of 3 or more. This tendency of the foils to shrink was overcome by depositing 100-300 Å of aluminum on the Parylene foils. One of these coated foils (1700 Å of Parylene and 300 Å of Al) maintained its width for several hours in a 6 μA/cm² dc average beam current. This foil had an H^- to H^o stripping efficiency of 10-15%, consistent with that expected from Fig. 3.

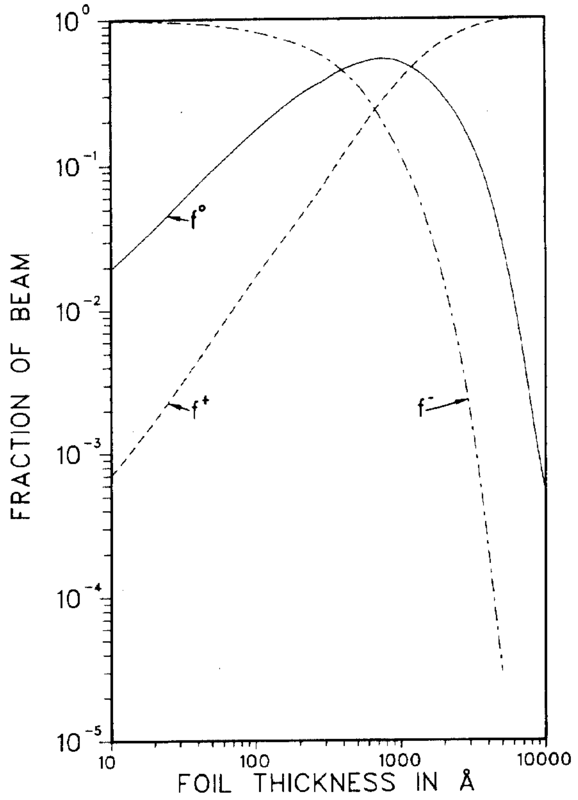

Fig. 3. Fractional Charge States Produced from a 50-MeV H⁻ Beam Incident on a Parylene Foil as a Function of Foil Thickness

During these studies, none of the foils or fibers broke during irradiation, but all showed an eventual shrinkage in width. The aluminum maintained the dimensional stability longer, but the extra thickness of aluminum caused a decrease in H^o stripping efficiency. Another approach, which showed considerable promise at maintaining the width, was to use 6 μm glass fibers as bracing between the 10 μm fibers. The best combination appears to be 600 Å Parylene foils with 100 Å of Al and 6 μm fibers for bracing. This combination is expected to survive several hours in the beam and yield an H^o stripping efficiency close to 50% with reduced radiation from the lower H^+ fraction.

Future Directions

At 50-MeV, the development of efficient $H^- \rightarrow H^o$ stripping foils has proven to be quite challenging. Foils for higher energy accelerators pose less of a problem due to the reduced stripping cross section. This will permit thicker foils with a greater thickness of aluminum coating. Foil survival and dimensional stability should be less of a problem due to the reduced energy deposition rate.

An interesting modification of this technique would be to use a scanned laser beam to produce photostripping of a fraction of the beam to H^0, with little H^+ contamination. The use of a several Megawatt laser could yield relatively high H^0 efficiency with no penetration of the scanning mechanism in the vacuum chamber. However, the greatest advantage with using photostripping may be that it could be appropriately timed to look at the time structure (phase) of the beam. The use of photostripping in this beam was not possible due to the large H^0 background, as well as the cost involved.

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References

1. R. Smythe and J. Toevs, Phys. Rev. 139A, 15 (1965).

2. Parylene is the generic name for a thermoplastic polymer developed by Union Carbide Corp., 270 Park Ave., New York, N.Y. 10017.