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HIGH EFFICIENCY BEAM SPLITTING FOR H^- ACCELERATORS

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Abstract

Beam splitting for high energy accelerators has typically involved a significant loss of beam and radiation. This paper reports on a new method of splitting beams for H^- accelerators. This technique uses a high intensity flash of light to strip a fraction of the H^- beam to H^o which are then easily separated by a small bending magnet. A system using a 900-watt (average electrical power) flashlamp and a highly efficient collector will provide 10^{-3} to 10^{-2} splitting of a 50 MeV H^- beam. Results on the operation and comparisons with stripping cross sections are presented. Also discussed is the possibility for developing this system to yield a higher stripping fraction.

Introduction

Methods used for splitting beams from high energy accelerators have typically used electrostatic or magnetic septa. Both methods require material structures in the beam which contribute to beam loss, radiation background, and induced radioactivity. With the recent increase in availability of high energy H^- ion beams for charge exchange injection into accelerators, the possible use of the charge exchange interaction for beam separation has become feasible.

In a previous paper[1], the use of charge exchange separation was used for measuring the H^- beam emittance, nondestructively. That method used a thin foil as the charge exchange interaction media, which yielded three charge states (H^-, H^o, and H^+) which are separated by a subsequent magnetic field. The ratio of these three components depends on the H^- energy and the foil thickness. In some cases, only a two-way separation is required and the third ion results in a beam loss or needless radiation background. This paper describes a method for achieving such a beam separation using the photo-detachment reaction. This method was developed in order to provide for increased intensity and an intensity control for a low-intensity, 50-MeV proton beam.[2]

Discussion of the Method

The photo-detachment of H^- ions has been of interest from the atomic physics of two-electron atoms.[3] Photons with energy above the ionization potential (0.75 eV) will neutralize the ion and will not ionize to H^+, provided the energy of the photon is less than 13 eV. The cross section[4] for this process has a maximum at a photon energy of about 1.5 eV of approximately 4×10^{-17} cm^2.

The stripping fractions, f_o = Number H^o/Number H^- incident, can be calculated using the approximate expression[5]

$$f_o = \frac{P(E)}{Ec}\,\frac{\sigma(E)}{\Delta} \quad ,$$

where $P(E)$ is the instantaneous light power incident orthogonal to the ion beam,
E is the energy of the photon beam,
Δ is the width of the photon beam (assumed equal to the ion beam width),
c is the velocity of light.

Even for stripping fractions of 10^{-2}, the light power required is about 2 MW for photons of 1.5 eV energy. The cost of providing this light power using a laser system is high, even with the multiple reflection scheme described in Ref. 5.

The pulsed nature of the high energy H^- beams and the broad cross section peak above 1.5 eV makes it possible to use a less expensive, high power and broad spectrum light source, such as a Xenon flashlamp. A linear flashlamp can be effectively coupled to the ion beam using an elliptical reflector similar to those developed for excitation of cylindrical laser rods.[6] In this case, the stripping fraction is given by

$$f_o = \frac{P_{el}\ \epsilon_{el}\ \epsilon_{geom}}{C}\, S\ D$$

where $$S = \int \frac{\sigma(E)\ \phi(E)}{E}\, dE,$$

$$D = \frac{1}{N_B} \int \rho_B(r)dr = \left(\frac{1}{5\sigma} \text{ for gaussian beam}\right),$$

$\phi(E)dE$ = the normalized light power spectrum,
$\rho_B(r)$ = the ion beam density,
N_B = $2\pi \int \rho_B(r)rdr$ = total number of ions,
ϵ_{el} = electrical-to-light power efficiency,
ϵ_{geom} = geometrical efficiency of the reflector system,
P_{el} = total electrical power.

Flashlamps with 8,000 amps/cm^2 average current have $S = 1.5 \times 10^{-17}$ cm^2/eV and $\epsilon_{el} = 0.3$. Elliptical reflectors can have a geometric efficiency of 0.4 to 0.6 depending on beam size and the eccentricity of the ellipse. Therefore, it is possible to achieve a stripping efficiency of 10^{-3} with approximately 1 MW of electrical power. In addition, the flashlamp pulse may be easily extended to match the time duration of the ion pulse.

This calculation represents an underestimation of the stripping fraction since it does not account for multiple reflections from the reflector. The actual fraction could be 2 to 3 times greater depending on the quality of the vacuum interface and the reflection coefficient of the reflector surface.

Experimental Results

The goal was to achieve a stripping efficiency of about 1×10^{-3} for the 50 MeV H^- beam from the Argonne linear accelerator. During normal operation, this accelerator produces 12 to 14 μamps of H^- beam at a 30 Hz rate for injection into the rapid cycling synchrotron (RCS). When the RCS is not operational, the linear accelerator can only operate at a 5 Hz rate, due to beam dump limitations. The light stripper will, therefore, enable the experimental uses of the 50 MeV proton beam to continue at a 1 namp intensity while maintaining the safety inherent in the H^o stripping process source of this beam.

An inexpensive elliptical reflector was built using an elliptical wooden form to form the reflector using polished aluminum foil supported by a fiberglass outer wall. Figure 1 shows a schematic of the light stripping system. The flashlamp[7] had an arc length of 15 cm and a bore diameter of 1.3 cm. The light was coupled to the beam through a 7.5 cm diameter quartz glass tube. The ends of the elliptical reflector had

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED aluminized walls perpendicular to the beam direction.

The flashtube power supply was capable of delivering more than 2 MW of electrical power during the 60 μsec long pulse and at a maximum rate of 5 Hz. The flashlamp circuit consisted of an L-C in series with the flashtube. This circuit produces a light power level which is not constant during the pulse, resulting in variation of the stripping fraction during the pulse. The series inductor also contributes to a lower initial voltage on the flashlamp and consequently increased time jitter (as seen in Fig. 2). An improved power supply might have a multi-stage pulse forming circuit to increase the firing voltage (reduce time jitter) and to improve the uniformity of the light intensity during the pulse.

Figure 2 shows the measured Faraday cup signal for the 50-MeV H^o beam with and without the flashlamp firing. Also shown is the voltage on the storage capacitor for the flashlamp. A factor of 18 increase in 50 MeV H^o intensity was observed with an electrical power of 1 MW for a 60-μsec pulse width. The measured stripping efficiency was about 2.5×10^{-3}. Although the beam pulse width was only 35 μsec, the stripping efficiency depends only on the light power. However, the same electrical energy would have yielded a higher fraction if a shorter pulse width was available.

Future Directions

Figure 3 shows an extrapolation of the stripping efficiency measured here up to the 10^9 watt level where stripping efficiencies approach the 90% level. Achievement of stripping efficiencies of this level will require development in the technology of handling such high peak light power and the resulting heating. Water-cooled flashlamps can easily handle this power level, but the beam vacuum interface and reflector may also need cooling. A better solution might be to reduce the beam pulse width an order of magnitude and also to increase the efficiency of the light coupling to the ion beam.

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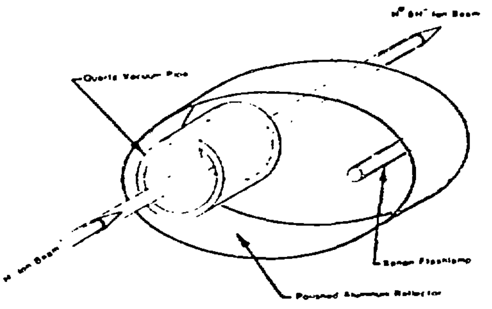

Fig. 1 Schematic Layout of Light Stripper System

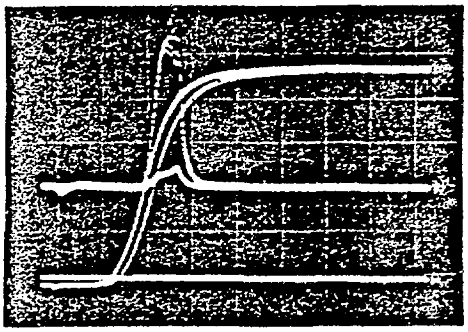

Fig. 2 Faraday Cup Signal With and Without the Flashlamp Firing (lower trace is the voltage on the storage capacitor)

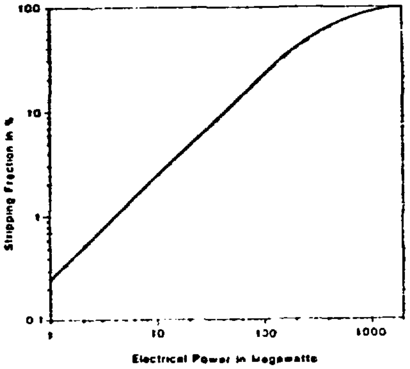

Fig. 3 Stripping Fraction vs. Electrical Power for a Flashlamp System. The data point at 10^6 watts is the measured Data for this study.