BNL-105126-2014-TECH

Booster Technical Note No. 79;BNL-105126-2014-IR

H- stripping in the Booster proton injector line

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May 1987

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U.S. Department of Energy

USDOE Office of Science (SC)

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A purely electric or magnetic field in one frame of reference will appear as a mixture of electric and magnetic fields in another frame of reference if the second coordinate system is in motion relative to the first. Therefore a particle moving at velocity v through a magnetic field of magnitude B will experience an electric field of magnitude E given by the Lorentz transformation[1]

$$E = \gamma v B = c\,\beta\gamma B \qquad \text{(MKS units)}$$

For the H^- injection line this electric field might cause stripping of the H^- ion to neutral hydrogen. The decay of H^- ions in an electric field can be represented by the differential equation[2]

$$\frac{df(t)}{dt} = -\frac{f(t)}{\tau(t)}$$

where $f(t)$ is the fraction of the beam remaining at time t, $f(t{=}0) = 1$, and $\tau(t)$ is the average lifetime of an ion in the field E in which the ion is moving at the time t. If the magnetic field is constant along the path of the particle then τ is constant and $f(t)$ is simply an exponential decay function.

The average lifetime of H^- ions as a function of the electric field strength has been found experimentally[3] to be

$$\tau(E) = \frac{7.96 \times 10^{-6}\ \text{Vs/m}}{E} \exp\left[\frac{4.256 \times 10^{9}\ \text{V/m}}{E}\right]$$

The H^- transfer line to the Booster requires that the ions bend through an angle of 126.165° (excluding the 7.5° bend at the kicker in the HEBT line and the 6.968° bend in Booster dipole magnet MDC5 through which the beam is injected). For 200 MeV H^- ions, $\beta = v/c, = 0.5662$ and $B\rho = 2.1496$ T-m. Therefore, since

$$BL = (B\rho)\,\theta$$

where θ is in radians, and BL is the product of the constant dipole field of the bending magnets in the H^- line and their total magnetic length,

$$BL = 1.1834\ \text{T·m}$$

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[1] John David Jackson, **Classical Electrodynamics**, p. 380.

[2] K. Prelec, "Stripping of H^- in a Magnetic Field," AGS Division Technical Note No. 110, June 4, 1974.

[3] G. M. Stinson, *et. al.*, Nucl. Instrum. Methods, **74**, 333 (1964).

Physical restrictions and construction requirements suggest the use of four bending magnets of equal length, l, so $L = 4l$. We wish to choose a length that gives insignificant stripping.

$$\% \text{ stripped} = 100\% \left[1 - e^{-t/\tau}\right]$$

where $t = 4l/v$ and τ is calculated from the equations given above. The results are shown in the table below. Ramesh Gupta, who is specifying the design of the H^- injection line, has chosen the values of 1.3 m and 0.91 T for the lengths and strengths of the four dipole magnets since these values give negligible ion stripping.

l (m)	B (T)	τ (μs)	t (ns)	% Lost (%)
0.5	2.367	1.01×10^{-4}	11.78	100.00
0.6	1.972	6.97×10^{-4}	14.14	100.00
0.7	1.691	4.66×10^{-3}	16.50	97.09
0.8	1.479	3.06×10^{-2}	18.85	46.04
0.9	1.315	1.97×10^{-1}	21.21	10.20
1.0	1.183	1.26	23.57	1.86
1.1	1.076	7.92	25.92	0.33
1.2	0.986	4.96×10^{1}	28.28	0.06
1.3	0.910	3.08×10^{2}	30.63	0.01
1.4	0.845	1.90×10^{3}	32.99	0.00
1.5	0.789	1.17×10^{4}	35.35	0.00
1.6	0.740	7.15×10^{4}	37.70	0.00
1.7	0.696	4.35×10^{5}	40.06	0.00
1.8	0.657	2.64×10^{6}	42.42	0.00
1.9	0.623	1.60×10^{7}	44.77	0.00
2.0	0.592	9.66×10^{7}	47.13	0.00