BEAM LOSS IN THE STORAGE RING COMPLEX DUE TO CHARGE EXCHANGE SCATTERING

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1. INTRODUCTION

We have estimated the beam loss due to charge exchange scattering for the three reference designs used during this study. The formula derived under simplifying assumptions is similar to that used previously by Mills[1]. Our results show that this effect is by no means negligible and indicate a need for both more complete calculations and further experimental data on charge exchange cross-sections for specific ions.

2. BEAM LIFETIME

In the lab. frame we have

$$d\dot{N} = v\sigma\rho^2 dV \quad , \tag{1}$$

where v = relative velocity, ρ = particle density, N = number of particles in a bunch of volume V and σ = event cross-section. All quantities are measured in the laboratory frame.

This leads to an e-folding time τ given by

$$\frac{1}{\tau} = \frac{1}{N}\int v\sigma\rho^2 dV \quad . \tag{2}$$

To evaluate the integral in equation (2) we make the following simplifying assumptions:

a) The relative velocity, v, is that due to betatron motion only and is an average relative velocity.

b) The cross-section, σ, is independent of the velocity.

c) The effect of storage ring dispersion on the particle density is neglected.

d) The particle density, ρ, is assumed to be uniform. However the maximum amplitude (which defines the beam emittance) is taken as twice the rms amplitude of a gaussian distribution.

The validity of these assumptions is commented upon later. Under these assumptions equation (2) may be written

$$\frac{1}{\tau} = \sigma v \frac{N}{V} \quad . \tag{3}$$

Now $V = 4\pi\langle x\rangle\langle y\rangle\ell$, and we take an average relative velocity $v = 2\beta c\langle x'\rangle$ where $\langle x\rangle$, $\langle y\rangle$ = rms transverse amplitudes, ℓ = bunch length and $\langle x'\rangle$ = rms angular spread, βc = particle longitudinal velocity.

We assume equal emittances in each transverse plane so that

$$\langle x\rangle = \langle y\rangle = \frac{1}{2}(\varepsilon\beta_x)^{1/2} \quad ,$$

where β_x = envelope function

and $\varepsilon = 4\langle x\rangle\langle x'\rangle$.

Substituting into equation (3) we obtain

$$\frac{1}{\tau} = \frac{N\sigma\beta c}{\pi\,\varepsilon^{1/2}\,\beta_x^{3/2}\,\ell} \quad . \tag{4}$$

We assume a uniform longitudinal particle distribution $\frac{N\beta c}{\ell} = \frac{I}{Ze}$, and on transforming the cross-section to the center of mass frame obtain

$$\frac{1}{\tau} = \frac{1}{\pi}\frac{I}{Ze}\frac{\sigma_{cm}}{\varepsilon^{1/2}\beta^{3/2}\gamma} \quad , \tag{5}$$

where we have dropped the subscript from the envelope function β.

The loss rate will vary around the ring due to the azimuthal variation of β. In evaluating equation (5) we therefore take an effective value of β defined by

$$\beta_{eff} = \left[1/2 \left(\frac{1}{\beta_{min}^{3/2}} + \frac{1}{\beta_{max}^{3/2}} \right) \right]^{-2/3} .$$

The resultant lifetimes, for a cross-section $\sigma_{cm} = 10^{-15} cm^2$, for each of the three reference cases are presented in Table 1. Values for β_{min} and β_{max} have been taken from Cornacchia and Rees[(2)].

TABLE 1

Case	A	B	C
β_{eff}(m)	6.2	6.2	6.2
ε(m.rad)	60×10^{-6}	60×10^{-6}	60×10^{-6}
$\sigma_{cm}(cm^2)$	10^{-15}	10^{-15}	10^{-15}
γ	1.0226	1.0451	1.0451
I(A)	6	17.1	24.3
τ(ms)	102	37	26

The present numbers assume a charge state 1.

3. COMMENTS AND CONCLUSIONS

Equation (5) shows that $\tau \sim \frac{\varepsilon^{1/2}}{I}$. We have used the final storage/compression ring parameters and these contain some allowance for emittance dilution. While the beam is being stacked in these or similar intermediate rings τ will be less than the quoted values by up to 40%. Since the minimum beam handling times between linac and final compression in the rings are respectively 0.7, 1.0 and 3.3 ms we would estimate the beam loss, using $\sigma_{cm} = 10^{-15}$ cm^2, to be at least 1/2%, 2.5%, and 12% respectively for cases A, B, and C.

We have used a somewhat arbitrary cross-section of $\sigma_{cm} = 10^{-15}$ cm^2 for the 'Uranium-like' ion. Recent measurement[(3)] on Cs^+ ions indicate that this may not be an unreasonble value. Clearly further measurements on other ion species are necessary. Intuitively it seems appropriate to select a closed-shell ion. However, if this leads to either a multiply charged ion of $A \gtrsim 200$ or a singly charged ion of $A < 200$ problems of space charge in circular rings would become exacerbated.

We made several assumptions (a) and (c) above seem equation (5). Assmptions (a) and (c) above seem justifiable since, for the uncompressed beams, momentum spreads are of order 10^{-4} while angular spreads are of order 10^{-3}. We have not attempted to consider the situation during compression in the rings because of significant perturbations to the lattice parameters by space charge effects and because the compression stage occurs over a relatively short time scale (60-100 turns, 400-600 μs).

To obtain an accurate assessment of the problem, complete calculations (numerical simulation?) should be performed using realistic 6-D distributions, including space charge effects, combined with the cross-section for loss (ionization may leave one particle within the ring acceptance) as a function of relative ion velocity.

REFERENCES

1. F.E. Mills, ERDA Summer Study of Heavy Ions for Fusion, LBL 5543, p. 79, (1976).
2. M. Cornacchia, G.H. Rees. These proceedings.
3. K.F. Dunn et al, 1979 J. Phys. B: Atom. Molec. Phys., Vol. 12, L623, (1979).