LIFETIME OF ION BEAM IN AN ACCUMULATION RING

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Beam loss due to charge exchange processes such as

$$A^{n+} + A^{n+} \rightarrow A^{(n+1)+} + A^{(n-1)+}$$

may be a severe obstacle to accumulating intense ion beams in a storage ring. Here, the loss rate is estimated for a ring where Xe^{4+} ions are supposed to be accumulated.

The loss rate is given by

$$\alpha \equiv \frac{1}{N}\frac{dN}{dt} \qquad (1)$$

$$= n_{lab} V_{cm} \sigma_{cm} \,. \qquad (2)$$

The symbols are defined in Table 1, where machine parameters are also listed. The density of ions in the ring is

$$n_{lab} = \frac{N}{2\pi RS} \,, \qquad (3)$$

on the assumption that the beam is completely debunched. The beam is to be stored in the ring as shown in Fig. 1. Then the cross section of the beam is

$$S = \pi ab + b\Delta x_p \,, \qquad (4)$$

where a and b are obtained from the beam emittance ε and the average betatron amplitude function, $\bar{\beta}$,

$$a = \sqrt{\varepsilon_x \bar{\beta}} \,, \qquad (5)$$

$$a = \sqrt{\varepsilon_y \bar{\beta}} \,. \qquad (6)$$

The beam spread due to a momentum dispersion is

$$\Delta x_p = \eta \frac{\Delta p}{p} \qquad (7)$$

The dispersion function is approximately

$$\eta = \bar{\beta}^2/R \qquad (8)$$

Then the beam cross section is numerically calculated with values listed in Table 1, and the density is

Table 1 List of Symbols and Machine Parameters

N	number of ions in the ring	2×10^{13}
n_{lab}	density of ions	
R	mean radius of the ring	140 m
S	cross section of the beam	
V_{cm}	velocity of ions in the center of mass frame	
α	loss rate	
β	ratio of ion velocity to that of light	
	0.507 (150 MeV/u)(~ 19.5 GeV) 0.204 (20 MeV/u)(~ 2.6 GeV)	
$\bar{\beta}$	average betatron amplitude function	13.7 m
γ	$1/\sqrt{1-\beta^2}$	
$\frac{\delta' p}{p}$	momentum difference between colliding ions	
$\frac{\Delta p}{p}$	total momentum spread	2.5×10^{-3}
ε_x	emittance in the horizontal direction	35×10^{-6} m-rad
ε_y	emittance in the vertical direction	18×10^{-6} m-rad
η	dispersion function	
θ	collision angle in the laboratory frame	
σ_{cm}	cross section of the electron transfer process	1×10^{-19} m^2
τ	life time	

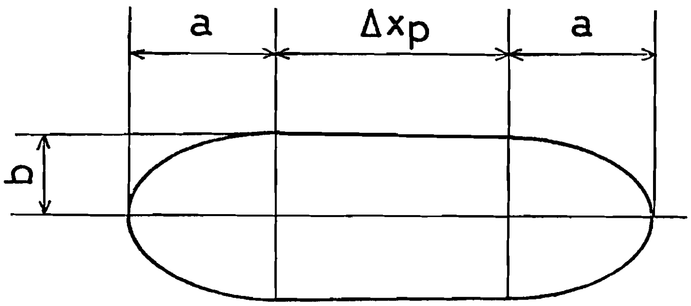

Fig. 1. The beam profile in the accumulation ring.

$$n_{lab} = 2.01 \times 10^{13} \ (m^{-1}) \ . \tag{9}$$

The speed of the ion in the center of mass frame is given by

$$\beta_{cm}^{2} = \left(\frac{\beta}{2}\frac{\delta' p}{p}\right)^{2} + \left(\beta\gamma \sin\frac{\theta}{2}\right)^{2} \tag{10}$$

As the momenta of ions are considered to be distributed as shown in Fig. 2, the typical momentum difference between the ions which will collide with each other, is

$$\frac{\delta' p}{p} = \frac{\Delta p}{p} \ \frac{2a}{2a + \Delta x_p} \ , \tag{11}$$

where $\delta' p/p$ is determined so that the areas of the parallelogram and the rectangle are equal. Then the first term of eq. (10) is 1.59×10^{-3} for 150 MeV/u and 6.50×10^{-4} for 20 MeV/u. The maximum collision angle in the laboratory is evaluated by

$$\theta = 2\sqrt{\epsilon_x/\beta} \ , \tag{12}$$

and the second term is numerically 1.56×10^{-3} for 150 MeV/u and 5.63×10^{-4} for 20 MeV/u. Then the velocity in the cm frame is

$$v_{cm} = \begin{cases} 3.27 \times 10^{5} \ (m/s) \ (150 \ MeV/u) & (13) \\ 1.24 \times 10^{5} \ (m/s) \ (20 \ MeV/u) \ . & (14) \end{cases}$$

As experimental data of cross sections for the electron transfer processes are scarce and there are no data for $Xe^{4+} + Xe^{4+} \rightarrow Xe^{5+} + Xe^{3+}$, so a theoretically predicted value is adopted. Macek estimated the cross section for $Xe^{8+} + Xe^{8+} \rightarrow Xe^{9+} + Xe^{7+}$ at much smaller than $10^{-18} cm^{2}$.(1) It is supposed that such a small cross section is due to a $4d^{10}$ closed outer shell configuration of a Xe^{8+}ion. In our case of Xe^{4+}, however, four electrons remain in the outer shell, so the cross section should be larger. According to papers presented at previous Heavy Ion Fusion Workshops(2) the cross sections for the electron transfer process of various ions are estimated to be of the order of $10^{-15} cm^{2}$. Therefore, a value of $1 \times 10^{-15} cm^{2}$ is adopted here.

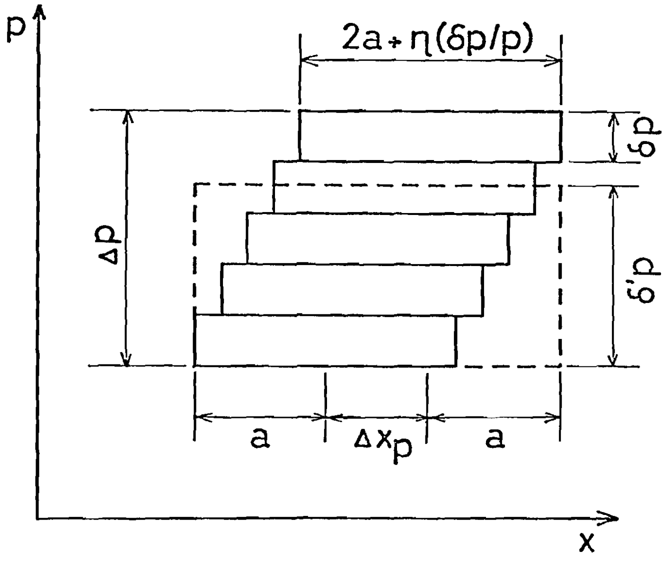

Fig. 2. Five beam pulses of different momenta are stacked in the accumulation ring. The typical momentum spread δ'p is determined so that the area of the rectangle (dashed line) and that of the five pulses are equal.

Now the loss rate can be numerically calculated, and

$$\alpha = \begin{cases} 0.657 \ s^{-1} & (150 \ MeV/u) \ , & (15) \\ 0.249 \ s^{-1} & (\ 20 \ MeV/u) \ . & (16) \end{cases}$$

The life time, the inverse of the loss rate, is

$$\tau = \begin{cases} 1.52 \ s & (150 \ MeV/u) \ , & (17) \\ 4.02 \ s & (\ 20 \ MeV/u) \ . & (18) \end{cases}$$

These lifetimes are long enough in a heavy ion fusion driver complex which includes an accumulation ring where about 10^{13}ions are stored.(3)

References:

(1) J. Macek, Proceedings of the Heavy Ion Fusion Workshop, Argonne, 1978, p. 183.

(2) Proceedings of the Heavy Ion Fusion Workshop, Berkeley, 1977, Proceedings of the Heavy ion Fusion Workshop, Argonne, 1978.

(3) T. Katayama and A. Noda. These Proceedings.