ONE SELF-NEUTRALIZATION MODEL OF BEAMS: NEW RESULTS

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1 INTRODUCTION

The neutralization effects are a limitation of accelerator performances at various occasions. Some of the difficulties of the first accelerators came from the fact that the vacuum systems were not good enough. The difficulties will rather be linked at the large currents and high densities especially of the circulating beams.

In this paper some new results are shown by using of one self - neutralization model of beams by ionization of the residual gases in accelerators. The loss of transmitted protons into a beam chamber due to charge changing collisions with the residual gas molecules is discussed for four different pressures in the region of 10^{-1} - 10^{-4} Pa.

2 ONE SELF-NEUTRALIZATION MODEL OF BEAM

One self - neutralization model of beam has also been published in papers [1-2]. It is assumed that the electron production is due mainly to collisions between beam ions and gas atoms and electron loss to be due to scattering out of the potential well of the beam. It holds that the electron production rate is given by

$$\frac{dn_e}{dt} = n_i n_o \sigma_{io} v_i \tag{1}$$

and the electron loss rate is given by

$$\frac{-dn_e}{dt} = \frac{n_e}{\tau} e^{\frac{-\phi}{T}} \tag{2}$$

where n_i is the ion density of the beam, n_o is the neutral density, σ_{io} is the cross section for ionization of the atoms by the beam ions, v_i is the beam ion velocity, n_e is the electron density, τ is the time for scattering of electrons by the ions in the beam, ϕ is the plasma potential (eV) and T is the electron temperature (eV).

The energy input is estimated from the heat- ing rate of the electrons by the beam ions being $n_e m_e v_i^2/2\tau$ where m_e is the electron mass. Hamilton [2] calculates the energy loss from the system by means of the ionization cross section σ_{io}, by the charge exchange cross section σ_x and by the transport potential energy ϕ from the system. He derived for the energy loss a rate of $n_i n_o v_i(\sigma_{io} + \sigma_x)\phi$.

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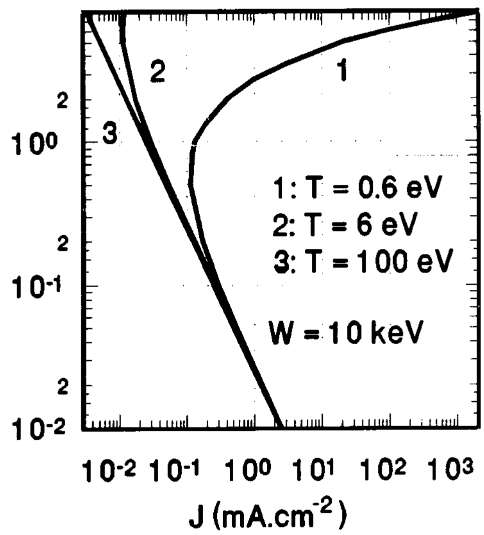

Figure 1: Beam potential Φ as a function of mean current density J for three different electron temperatures T (T = 0.6, 6 and 100 keV) at energy of protons W = 10 keV.

Finally, it is assumed that the beam ion density n_i is approximately the same as the electron density n_e, i.e. $n_e \approx n_i$. The effect of slow ions is also neglected completely. After it, than the two equations for particle and power balance can be reduced to the form

$$n_o \sigma_{io} v_i = \frac{1}{\tau} e^{\frac{-\phi}{T}} \tag{3}$$

and

$$n_o(\sigma_{io} + \sigma_x) v_i \phi = \frac{m_e v_i^2}{2\tau}. \tag{4}$$

Further W = $\frac{M v_i^2}{2}$ = eV where eV is the energy and M is the mass of ions, respectively. Hence

$$\frac{\phi}{T} = 2.3 log\left(\frac{M}{m_e}\frac{\phi}{eV}\frac{\sigma_{io} + \sigma_x}{\sigma_{io}}\right). \tag{5}$$

For typical parameters of the hydrogen beam at energy W = 10 keV and pressure p = 10^{-4} Pa

J = 0.1 mA cm^{-2}	v_i = 1.4x10^8 cm s^{-1}
n_i = 4.46x10^6 ions cm^{-3}	n_o = 2.645x10^{10} cm^{-3}
σ_{io} = 0.2x10^{-16} cm^2	σ_x = 4.3x10^{-16} cm^2

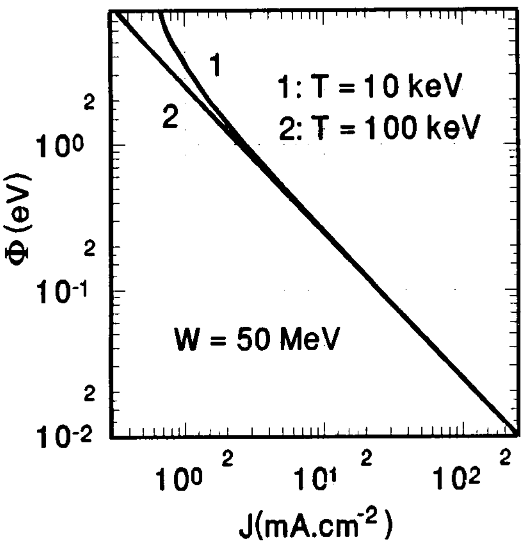

Figure 2: Beam potential Φ as a function of mean current density J for two different electron temperatures T (T = 10 and 100 keV) at energy of protons W = 50 MeV.

is the ratio

$$\frac{\phi}{T} = 10.622 + 2.3log(\frac{\phi}{T}). \qquad (6)$$

One can see that the potential $\phi \approx$ 7.9 eV for the temperature of electrons T_e = 0.6 eV.

The electrons produced in ionization have, in general, a finite energy of several volts which must contribute to the energy input. If $\sigma_{io} \rightarrow 0$ and $\sigma_x \rightarrow \infty$ the energy transported away from the system by the cold ions comes from the beam ions directly and not from the electron gas. However, the correction terms appear in the logarithm form and therefore do not produce a large effect.

The assumption of quasi - neutrality is also conserved when the beam density J is introduced for $n_i \approx n_e$ by equation

$$\mathrm{J} = 0.5 n_e m_e v_i^3 (\frac{\sigma_{io}}{\sigma_{io} + \sigma_x}) \frac{e^{\phi/T}}{\phi}. \qquad (7)$$

In order to illustrate results by the last equation Figure 1 and Figure 2 are shown.

The maximum derived beam potential energy ϕ is 8 eV at the different electron energies T and the different mean current densities. It is also seen a maximum of the density J at the electron temperature T = 0.6 eV and the beam potential ϕ = 1 eV. Definite maximum exist also at the higher electron energies but there are shifted to the higher values of the potential ϕ. If only the losses due to collisions between beam ions and residual gas atoms and electron loss to be due to scattering out of the potencial well of the beam, the losses of ions can be given by

$$\frac{-dn_i}{dt} \leq 79.240 n_e p \frac{(\sigma_{io} + \sigma_x)\phi}{m_e v_i} e^{\frac{-\phi}{T}} \qquad (8)$$

where ϕ is the plasma potential (eV), T is the electron temperature (eV), p is the pressure of residual gas (Pa) at the ambient temperature of 20 °C and other quantities are in SI units. Using just this ratio one can see the linear dependence of the ion losses on the pressure p.

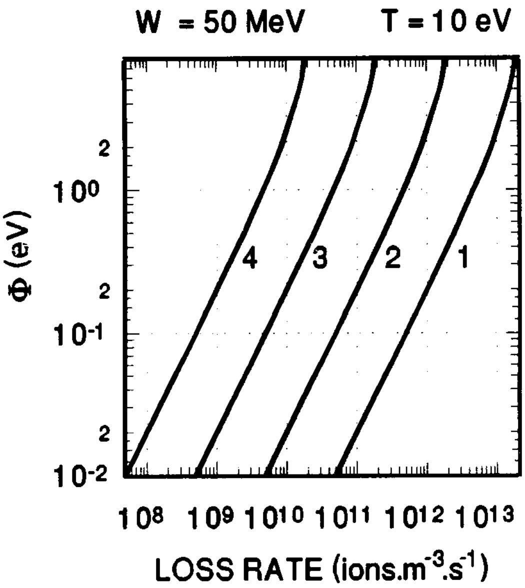

Figure 3: Beam potential Φ as a function of loss rate of protons for four different pressures p into the beam chamber (1: p = 10^{-1} Pa, 2: p = 10^{-2} Pa, 3: p = 10^{-3} Pa and 4: p = 10^{-4} Pa) at the electron temperature T = 10 eV and at the energy of protons W = 50 MeV.

In order to illustrate results by the equation (8) Figure 3, Figure 4 and Figure 5 are shown.

The maximum derived beam potential energy ϕ is also 8 eV but at the different electron energies T and the different loss rates of the proton beam. It is also seen a maximum of the proton beam loss rates -$\frac{dn_i}{dt}$ at the proton investigation energies of 50 MeV and 10 keV, respectively. Further, one can observe that the higher is the energy of protons the less is the loss rate at the same residual gas pressure.

The complete discussion of the self - neutralization process for the beam transport technology is complicated. It must include not only an analysis of electron production and loss in a completely self - consistent potential distribution, but also it has to be including beam fluctuations, magnetic fields and three dimensional variation of the beam density.

A certain measure of quasineutrality of the beam can also be the Debye length λ_D defined by equation λ_D = 4.9 $(T/n)^{1/2}$ where T is the temperature of ions (electrons) (K) and n is the density of ions (electrons) (cm^{-3}) [3]. The beam is quasineutral provided that its dimensions are less as λ_D, i.e. D < λ_D where D is the diameter of the beam. This condition reduces to

$$J < 3.2\mathrm{x}10^{-8} \mathrm{T}\sqrt{\mathrm{W}} \qquad \text{for protons} \qquad (9)$$

where J is the beam current (A), T is the electron temperature (eV) and W is the energy of protons (eV).

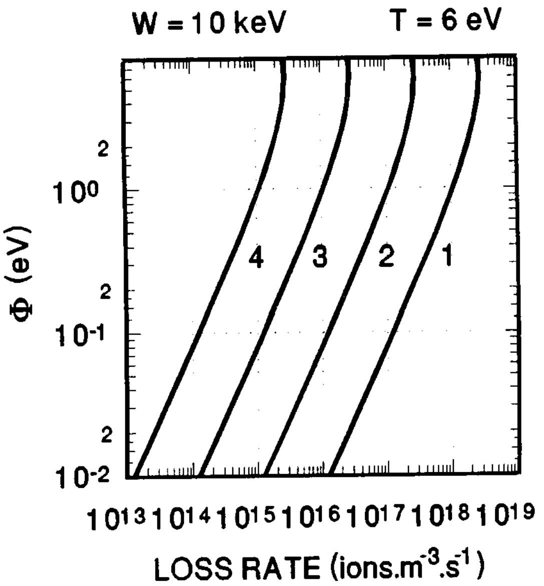

Figure 4: Beam potential Φ as a function of loss rate of protons for four different pressures p into the beam chamber (1: p = 10^{-1} Pa, 2: p = 10^{-2} Pa, 3: p = 10^{-3} Pa and 4: p = 10^{-4} Pa) at the electron temperature T = 6 eV and at the energy of protons W = 10 keV.

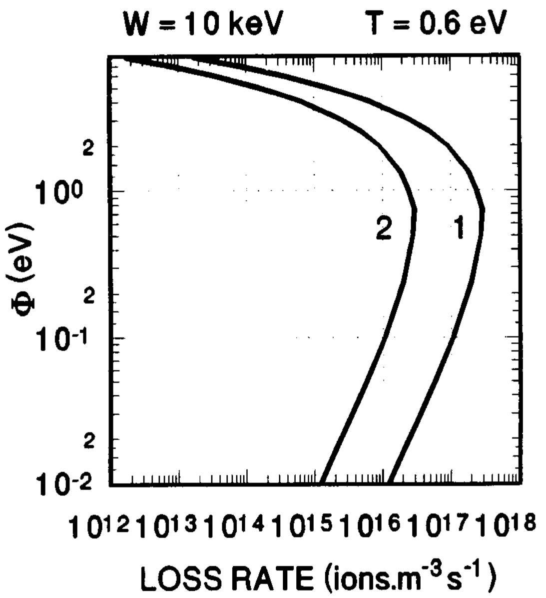

Figure 5: Beam potential Φ as a function of loss rate of protons for two different pressures p into the beam chamber (1: p = 10^{-1} Pa, 2: p = 10^{-2} Pa) at the electron temperature T = 0.6 eV and at the energy of protons W = 10 keV.

3 CONCLUSION

The losses of investigated protons due to collisions between beam ions and residual gases are linearly depended on the pressure p.

4 REFERENCES

[1] G.W. Hamilton, Proc. of Symp. of Ion Sources, Brookhaven BNL 50310, 171 (1971).

[2] T.S. Green, Reports on Progress in Physics **37,** 1257-1344 (1974).

[3] V.E. Golant, A.P. Zhilinskij, I.E Sacharov, Osnovy fiziki plazmy, Atomizdat, Moskva 1977, p.11.