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BEAM-LIFE AND VACUUM IN TRISTAN MAIN RING

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ABSTRACT

The relation between beam lifetime and pressure in TRISTAN main ring (MR) at the colliding energy (26 GeV) was investigated. The correlation of the lifetime with a partial pressure of CO was very good. A caluculated lifetime agrees with measured value within an error of pressure measurement.

INTRODUCTION [1,2,3]

An electron or positron of the stored beam changes its direction and energy by the collision with an atom of the residual gas. The change of the direction induce a betatron oscillation. If the amplitude of the oscilation exceeds an aperture of the beam duct at some point, the electron will be lost. Denoting the change of a direction by θ, the envelope of the betatron oscilation is:

$$\sqrt{\langle\beta\rangle}\sqrt{\beta(s)}\,\theta$$

where β = betatron function,
s = azimuthal parameter,
< > means an average over the ring.

In MR, the limit for this amplitude is imposed at QC1 or QC2 magnet near the collision point where β is large vertically or horizontally. An estimation gives for a critical θ above which the beam suffers a loss, about

$$\theta_c = 1\times 10^{-3}\ \mathrm{rad} \qquad (1)$$

If an electron losses a certain energy, say ε, the electron starts an energy oscillation and a horizontal betatron oscillation and a shift of an equilibrium orbit associated with the energy oscillation. If ε is larger than the energy aperture, the electron will get out of the bunch and be lost. This limit is given as:

$$\varepsilon_c/E < \text{Bucket height}$$

where E is a beam energy of a synchronous electron. And the bucket height for 26 GeV is about

$$1\times10^{-2}. \qquad (2)$$

An amplitude of horizontal oscillation is approximately expresed as:

$$\sqrt{(2\beta_x(s)\alpha R/\nu_x)}\cdot(\varepsilon/E)$$

where α = momentum compaction factor,
R = mean radius,
ν_x= horizontal tune.

The aperture limit at QC2 gives:

$$\varepsilon_c/E < 2.3\times10^{-2}.$$

So for an energy change, the limit of energy aperture is critical.

The beam-gas interactions which are important for the beam lifetime are as follows:

Rutherford Scattering

This is an elastic scattering by an atomic nucleus of the residual gas molecules. The cross section of beam loss for relativistic electron is:

$$\sigma_{\mathrm{Rutherford}} = 2\pi r_0^2Z^2\cdot 2/(\gamma^2\theta_c^2) \qquad (3)$$

where r_0= classical electron radius,
γ= primary energy in units of rest energy,
Z = atomic number.

MØller Scattering

This is an inelastic scattering on a bounded electron in a molecles. The cross section is:

$$\sigma_{\mathrm{M\O ller}} = 2\pi r_0^2/q \qquad (4)$$

where $q = \min(\gamma_c\ ,\ \gamma^2\theta_c^2/2)$,
$\gamma_c = \varepsilon_c$ in units of rest energy,
and $\gamma \gg 1$ is assumed.

Bremsstrahlung

This is a radiative energy loss process, and most effective. Deflection is negligible for relativistic electrons. Assuming $\gamma\gg1$, the cross section is

$$\sigma_{\mathrm{Brems}} = 4\alpha r_0^2Z(Z+1)\,[4/3\cdot\ln(\gamma/\gamma c)-5/6]\times\ln(183/Z^{1/3}) \qquad (5)$$

where α = fine structure constant.

Ionization and Excitation

This process is not so important as Bremsstrahlung at $\gamma\gg1$. This appears in relation to an ion trapping. But in the colliding mode of MR, almost equal currents of electron and positron exist. So the ion trapping need not be discussed here.

VACUUM CHARACTERISTICS

In the arc section of MR main gas components with a stored beam at 26 GeV are hydrogen (m/q = 2) and m/q = 28. A component whose m/q = 28 is assumed to be carbon monoxide (CO). Their densities are comparable. Since the cross sections listed above are proportional to Z or Z^2 (notice that $\sigma_{\mathrm{M\O ller}}$ should be multiplied with Z when applied for an atom with Z electrons), the partial pressure of CO determines the beam lifetime.

Fig.1 shows a variation of the pressure of CO due to synchrotron radiation (July 19, 1987). Beam energy was 26 GeV. Beam current is a sum of electron current and positron current. The pressure rise changes almost linearly with beam current. Neglecting the difference of desorption rates by electron and positron, the pressure can expressed as:

$$P = P_0 + DI, \qquad (6)$$

where P_0 = base pressure (of CO),
D = desorption rate,
I = total current.

BEAM LIFETIME

Using eq. (3), (4) and (5), the beam lifetime (τ) due to residual CO gas is expressed as:

$$1/\tau = 1/\tau_q + K\,[\,\sigma(6) + \sigma(8)\,]\,cP$$

$$\equiv 1/\tau_q + 1/\tau_0 \cdot (P/P_0) \qquad (7)$$

$$= 1/\tau_q + 1/\tau_0 \cdot (1 + D/P_0 \cdot I) \qquad (8)$$

where τ_q= lifetime independent of pressure
K = conversion coefficient from pressure to density,
c = velocity of light,
$\sigma(Z) = \sigma_{Rutherford}(Z) + \sigma_{M\o ller}(Z) + \sigma_{Brems}(Z)$.

Using values of (1) and (2) $\tau_0 P_0$ in Eq. (7) can be estimated as:

$$\tau_0 P_0 = 1.95\times10^{-2}\ \text{Pa}\cdot\text{sec} \qquad (9)$$

Fig.2 shows $1/\tau$ versus P in the same day and same position as in Fig.1. It is clearly shown that $1/\tau$ varies linearly with P. This figure gives:

$$\tau_q = 27.8\ \text{hour and}$$

$$\tau_0 P_0 = 1.25\times10^{-2}\ \text{Pa}\cdot\text{sec}. \qquad (10)$$

τ_q may correspond to the quantum lifetime. The deviation of factor 1.5 between (9) and (10) can be explained as, (i) while P in Eq. (7) should be considered as an average pressure over the whole ring, the pressure given in Fig.2 is a value of one point in the arc section, (ii) P in Fig.2 may contain a calibration error. So (10) seems to show rather good agreement with (9). This rough agreement and linear dependence of $1/\tau$ on CO pressure shows that among the residual gas mainly CO molecule contributes to the beam lifetime. $1/\tau$ - P relation using (9) is shown in Fig.2 as a broken line.

Fig.3 shows $1/\tau$ versus I. This figure gives $1/\tau_q + 1/\tau_0$ and using τ_q in Fig.2, τ_0 is given as:

$$\tau_0 = 17.4\ \text{hour}.$$

This is a beam lifetime corresponding to the base pressure. From Fig.1, P_0 and D in Eq. (6)can be obtained as:

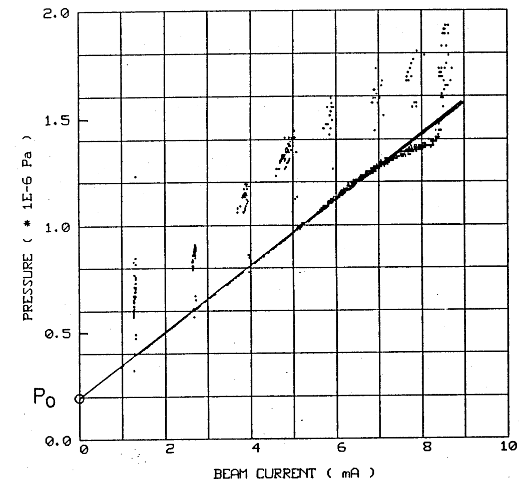

Fig.1 Pressure rise of CO due to synchrotron radiation (26 GeV). Beam current is the sum of electron current and positron current.

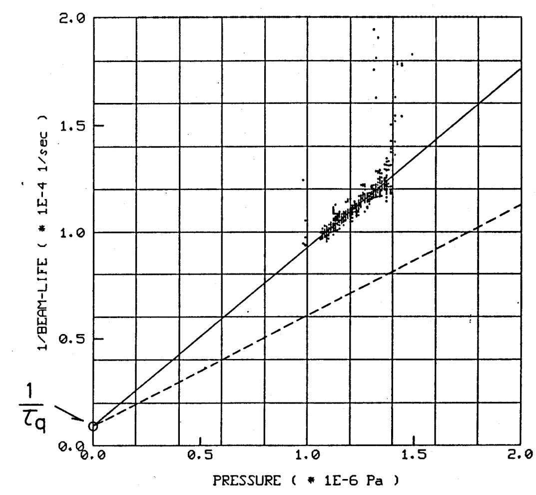

Fig.2 Beam lifetime and CO pressure

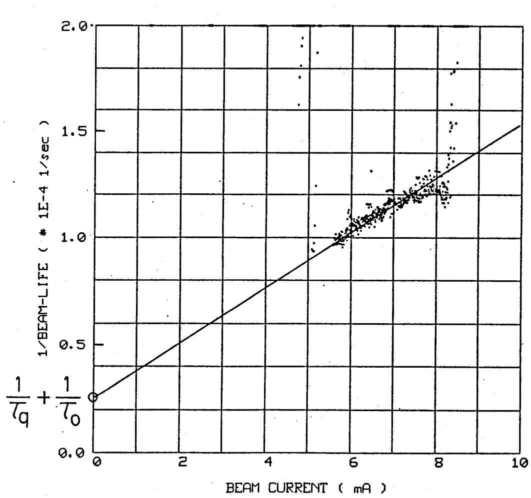

Fig.3 Beam lifetime and beam current

$P_o = 2.0 \times 10^{-7}$ Pa and $D = 1.5 \times 10^{-7}$ Pa/mA.

Combined with above τ_o, the slope of $1/\tau$ - I curve is evaluated to be:

$$1/\tau_o \cdot D/P_o = 1.2 \times 10^{-5}\ 1/\text{sec/mA}$$

This value is agree quite well with the actual slope. Thus Fig.1, Fig.2 and Fig.3 are mutually consistent.

REFERENCES

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3) W. Heitler, Quantum Theory of Radiation, Oxford, 1953.