Heating of the anodes of the integrated ion pumps in LEP-8 by scattered synchrotron radiation

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1. Estimate of the absorbed power

$$P_{\text{abs}} = P_{\text{lin}} k \delta (1 - e^{-\mu_a d})$$

- $P_{\text{lin}}$ = linear power density incident on the outer wall of the vacuum chamber (W/m)
- $k$ = fraction of backscattered radiation
- $\delta$ = fraction of the angle covered by the anode
- $\mu_a$ = mass absorption coefficient for the anode material and for the scattered photon energy (which will be lower than the primary photon energy) (cm$^2$/g).
- $d$ = equivalent mass thickness of the anode (g/cm$^2$).

For the case of LEP-8 we can use the following figures:

(i) $P_{\text{lin}}$ =

- 0.9 kW/m for 85 GeV
- 3.9 kW/m for 130 GeV

(ii) $k$

- 0.40 for 85 GeV
- 0.27 for 130 GeV

These values for $k$ were obtained from an EGS-calculation for monoenergetic primary photons of 0.3 and 1.4 MeV respectively. The angle of incidence on the vacuum chamber is 7 mrad. A calculation which takes into account the photon spectrum at these two machine energies yields even
slightly lower values.

(iii) the geometrical factor $\delta$ for the pump anodes is 0.11 for the LEP-8 design

(iv) the mass absorption coefficient for the stainless steel anode can be taken as:

$$\mu_a = 0.045 \text{ cm}^2/\text{g for 0.22 MeV photons, which is the average energy of the scattered 0.3 keV primary photons.}$$

Similarly, the 1.4 MeV primary photons will have an average energy of 0.72 MeV after scattering. The mass absorption coefficient for iron at this energy is\(^2\)

$$\mu_a = 0.028 \text{ cm}^2/\text{g}$$

(v) the equivalent mass thickness of the anode structure, which consists of 5 layers of 0.3 mm thick stainless steel with holes of 50 mm and 25 mm diameter has been determined from its total weight which is 225 g/m. If it is assumed that an equivalent absorber of this weight covers the same angular region as the anode structure, the its mass thickness amounts to 0.45 g/cm\(^2\).

The fraction of scattered radiation absorbed in the anode can thus be estimated as $(1 - e^{-\mu_a d}) = 2.10^{-2}$ for 85 GeV and $1.25 \times 10^{-2}$ for 130 GeV.

(vi) The total power absorbed in the anode is obtained as

$$P_{\text{abs (85 GeV)}} = 0.8 \text{ W/m}$$

$$P_{\text{abs (130 GeV)}} = 1.45 \text{ W/m}$$
2. To estimate the temperature rise, it has been assumed that the anode can lose the absorbed power only by radiation to the surrounding cooled vacuum chamber and to the pump cathodes which have to be in thermal contact with the chamber (note that cooled cathodes are essential for the good functioning of the pumps, even in the absence of radiation).

The anode temperature $T_A$ will therefore be given by

$$T_A^4 = \frac{P_{\text{abs}}}{\varepsilon_{\text{rel}} \cdot \sigma \cdot A} + T_W^4$$

where $\sigma = 5.67 \cdot 10^{-12}$ W/cm$^2$ grad

$A =$ total radiating surface, $1.87 \cdot 10^3$cm$^2$/m for the LEP-8 design

$T_W =$ temperature of the chamber, e.g. 300 K.

The relative emissivity $\varepsilon_{\text{rel}}$ has to be large to obtain good heat loss from the anode. By assuming emissivity values typical for clean steel and for clean aluminium, one finds $\varepsilon_{\text{rel}} = 3 \cdot 10^{-2}$. This value is certainly a pessimistic lower limit because, due to the sputtering of titanium during pump operation it is likely that this value will increase by up to one order of magnitude.

The estimated temperature rise of the anodes is therefore $21^\circ$C at 85 GeV operation and $35^\circ$C at 130 GeV, even under pessimistic assumptions. One may therefore conclude that there is a sufficient safety margin for the anode temperature.

References
