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Heat dissipation in a thin window near the focus of the SEB

T. E. Toohig

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

EP & S DIVISION TECHNICAL NOTE

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T.E. Toohig
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HEAT DISSIPATION IN A THIN WINDOW NEAR THE FOCUS OF THE SEB

There are a number of desirable aspects, both from the viewpoint of the AGS Division personnel and of experimenters using secondary beams, to terminating the AGS vacuum in the SEB line with a thin window just upstream of the S93 target. Such advantages as the increased simplicity of targetting in air, the reduced interaction between experimenter-controlled equipment and the AGS vacuum, and reduced multiple scattering in secondary beams might be cited. The greatest question mark in terminating the vacuum at this point is the possibility of rupture of the window by local heating by the concentrated beam spot so close to focus. For simplicity we will calculate this heating on the assumption of an aluminum window. Beryllium or titanium might also be used with factors of two in either direction relative to aluminum.

The ionization energy loss, dE/dx, in aluminum is 4.37 MeV/cm or 4.25×10^{-16} cal/mil/proton. Assuming a beam spot size of 40 mils x 100 mils the heating due to ionization in the thin window is given by:

$$\frac{\Delta Q}{\Delta t} = \frac{dE}{dx} \times I_o \times \frac{1}{t} \Big/ \rho\frac{dV}{d\ell}$$

where:

$\frac{dE}{dx}$ = energy loss/unit length

I_o = incident beam intensity/pulse

$\frac{1}{t}$ = machine pulse rate

$\rho\frac{dV}{d\ell}$ = mass per unit length in which energy is deposited.

$$\frac{dQ}{dt} = \frac{4.25 \times 10^{-16} \ \frac{\text{cal}}{\text{mil-proton}} \times 10^{13} \ \frac{\text{protons}}{\text{pulse}} \times \frac{1 \text{ pulse}}{2 \text{ sec.}}}{4.43 \ \frac{\text{g}}{\text{in}^3} \times 4 \times 10^{-6} \ \text{in}^3}$$

$$\boxed{\frac{dQ}{dt} = 12.0 \text{ cal/g/sec.}} \qquad \text{for 1 mil}$$

If the ΔQ for one pulse were all deposited instantaneously, the resultant temperature rise would be

$$\Delta T\ (A\ell) = 110^\circ C/\text{pulse}$$

similarly $\Delta T\ (Be) = 55^\circ C/\text{pulse}$

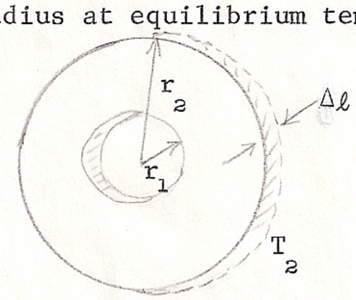
$$\Delta T\ (Ti) = 150^\circ C/\text{pulse}$$

using $c_p\ (A\ell) = 0.215$ cal/g C°

$c_p\ (Be) = 0.436$ cal/g C°

$c_p\ (Ti) = 0.125$ cal/g C°

In estimating the effectiveness of heat conduction by the window in dissipating the heat generated by the beam we consider the vacuum pipe an infinite sink in good thermal contact with the window. To first approximation we average the beam energy over the 2 sec cycle of the AGS and consider a steady state solution with this continuous source at the center of the window. We consider a disc of thickness $d\ell$ with a source disc of 37 mils radius at equilibrium temperature T_i.



For the steady state approximation:

$$\frac{dQ}{dt} = C = \frac{-kA_1}{\Delta\ell}\frac{dT_1}{dr_1} = \frac{-kA_2}{\Delta\ell}\frac{dT_2}{dr_2}$$

where $\frac{dQ}{dt}$ = heat input per unit thickness

A_i = the area of the disc edge at radius r_i

$= 2\pi\ r_i\ ds$

k = conductivity

T_i = steady state temperature at radius r_i.

C = constant

$$\frac{dQ}{dt} = C = - \frac{k\,2\pi r \Delta \ell}{\Delta \ell} \frac{dT}{dr}$$

$$dT = - \frac{c}{2\pi k} \frac{dr}{r}$$

$$\boxed{T_2 - T_1 = \Delta T = - \frac{c}{2\pi k} \ \ell n \frac{r_2}{r_1}}$$

$$\Delta T = \frac{2.15 \times 10^{-3} \dfrac{\text{cal}}{\text{sec-mil}} \times \ell n \dfrac{1.5 \text{ in.}}{.037 \text{ in.}}}{2\pi \times 1.22 \times 10^{-3} \dfrac{\text{cal}}{\text{sec-mil-C}^{\circ}}}$$

$$\boxed{\Delta T \approx 1^{\circ}\text{C}}$$

This first order temperature rise due to radiative loss by 10^{13} protons in the end window is small enough so more exact calculations do not seem warranted.

A 3-mil $A\ell$ window on the 3-inch vacuum pipe upstream of the S-93 target seems to be a reasonable vacuum termination even at conversion intensities of 10^{13} protons/pulse.

Distr: Administrative Staff
EP & Staff
R. Blumberg
R. Dryden
W. Gefers
J. Grisoli
L. Repeta
J. Schuchmann