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A Thick Target for Synchrotrons and Betatrons

E. M. McMillan

September 19, 1950

Berkeley, California

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A Thick Target for Synchrotrons and Betatrons

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The targets ordinarily used in electron synchrotrons and betatrons are very thin compared to the range of the electrons. This is satisfactory for most research purposes where a narrow beam of x-rays is desired; Schiff[1] has shown that thickening the target mainly increases the width of the beam with little gain in central intensity, and furthermore the distortion of the x-ray spectrum due to multiple radiative processes in a thick target is usually undesirable. In a platinum target only 0.020 inch thick, which converts about 15 percent of the electron energy into radiation, this distortion is already appreciable and must be corrected for in some experiments.

However one can imagine cases where a thick target would be useful, as for example in radiographic work where a wide beam is wanted in order to cover large objects. It is difficult to make the circulating beam traverse a thick target directly because of the very small spacing between successive turns. But suppose that the beam first passes through a very thin target, mounted as a projecting fin on the edge of a thick target, as shown in the figure. The energy loss in the fin will make the beam pass at a smaller radius on the next time around, striking the thick target. Scattering in the fin will have a similar effect (scattered electrons may make more than one turn before hitting the target). Of these two mechanisms, the energy loss by ionization is preferable since it is constant in magnitude, preserving the sharpness of the focal spot.

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[1] L. Schiff, Phys. Rev. 70, 87 (1946)

Therefore the fin should be made of a low-Z material, such as beryllium.

Let the fin have a surface density of N mols/cm^2 and atomic number Z. Then the ionization energy loss ΔW for electrons between 1 and 300 Mev in solid materials is given reasonably well[2] by:

$$\Delta W = 3.6\ ZN\ (\text{Mev}). \tag{1}$$

If the electron energy W is in Mev, the r.m.s. scattering angle α_o is given by:

$$\alpha_o = 1.0\ (Z/W)N^{1/2}\ (\text{radians}). \tag{2}$$

The energy loss causes a decrease $(1 - n)^{-1}(r\Delta W/W)$ in the radius of the instantaneous orbit. (r = orbit radius in cm, n = field index = $-(r/H)(\partial H/\partial r)$, $W \gg mc^2$.) The electron oscillates about the new instantaneous orbit with the frequency $(1 - n)^{1/2}$ times the circulation frequency. These facts, together with (1) and (2) and the assumption that the initial orbit is circular, lead to the following expression for the radial displacement Δr at an angle θ following the passage through the fin. The magnetic field H is in kilogauss, and the displacement due to scattering is given a ± sign and a magnitude corresponding to α_o:

$$\begin{aligned}\Delta r = 3.3\ (Z/H) \Big\{ & 3.6 \left[N/(1 - n)\right] \left[\cos\ (1 - n)^{1/2}\ \theta - 1\right] \\ & \pm \left[N/(1 - n)\right]^{1/2} \sin\ (1 - n)^{1/2}\ \theta \Big\}\ (\text{cm}).\end{aligned} \tag{3}$$

The corresponding axial displacement is

$$\Delta z = \pm\ 3.3\ (Z/H)\ \left[N/n\right]^{1/2} \sin\ n^{1/2}\ \theta\ (\text{cm}). \tag{4}$$

As a numerical example, consider a betatron with H = 3 kilogauss and n = 3/4. Let the fin be of beryllium (Z = 4) and have a thickness of 0.002 inch (N = 0.00104 mol/cm^2). Then, at $\theta = 2\pi$, the radial displacement, due entirely to the energy loss, is constant at -1.3 mm, while the axial distribution in the spot is Gaussian with a standard deviation of 1.2 mm. If n is increased to 0.8 while the other conditions remain the same, the spot becomes circular with radial

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[2] O. Halpern and H. Hall, Phys. Rev. 73, 477 (1948)

and axial standard deviations of 1.0 mm, and the radial displacement of its center becomes - 1.5 mm.

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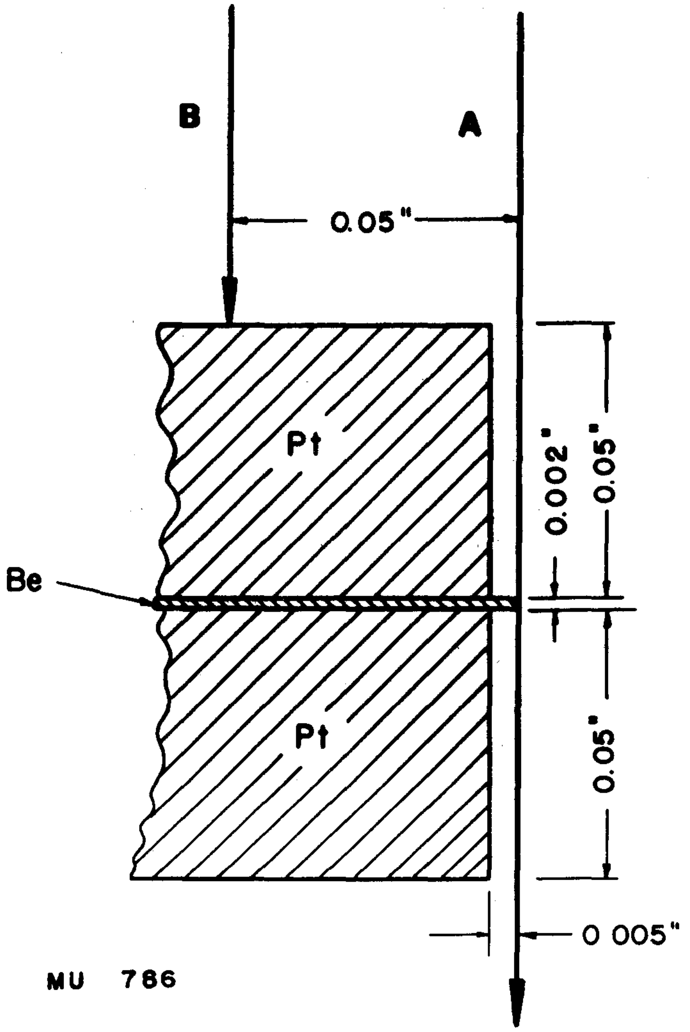

An electron following the orbit A (with its center to the left) passes through the beryllium fin, losing 15 Kev of energy; on the next time around it follows the path B, passing through the thick target. Dimensions correspond to the case given in the text, with H = 3 kilogauss, n = 3/4. An electron passing through the platinum target shown loses about 7 Mev by ionization.