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Subject: Temperature Rise in Iron Beam Position Monitors

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ABSTRACT. This note presents the results of EGS calculations for the temperature rise in an iron beam position monitor strip in the SLC arcs for a 50 GeV incident electron beam. Temperature rises of about 830° C/pulse are possible for 50μ (Gaussian σ) beams of $5 \times 10^{10} e^-$ /pulse if the angle of incidence is great (i.e., around 30 mradians).

For more realistic angles of incidence (i.e., between 2 and 4 mradians), the temperature rise is between 12 and 120° C/pulse (see Fig. 4). For steady state calculations, 1.7% to 3.8% of the total beam energy may be deposited in the BPM strip (see Fig. 5). These calculations indicate that it may be prudent to make the BPM strip out of aluminum.*

INTRODUCTION.

One problem encountered with beam position monitors (BPM) has been failure due to excessive heating. This usually occurs due to missteering of a beam somewhere. In one case recently, a BPM actually sagged into the beam. To preclude this, the BPM's associated with SLC have been designed to be 'shadowed' by various items, i.e., beam pipe, flanges, etc., such that the primary beam should never be able to strike the sensitive elements. However, a beam striking upstream somewhere can initiate a shower with some of the beam energy being deposited in the BPM downstream. The amount, and character, of that energy deposition will depend greatly upon the angle of incidence of the electron beam on the beam pipe.

Figure 1(a) shows a cutaway view of the upper half of a BPM along with the flanges and part of the beam pipe. Also shown on the same figure (b) is the EGS representation. We note that in the somewhat simplified EGS representation, the geometry isn't cylindrical as in the real world, but is composed of slabs that are essentially infinite into and out of the page. This isn't expected to have much effect on the final answers, and is the same type geometry used in earlier EGS calculations on heating of the beam pipe¹ and of the Lambertson magnet². Also in this geometry, the flexible bellows between the Al/Fe coupling and the Fe/BPM-face has been replaced by a vacuum since it was difficult to know just where the bellows, or what its total material path length, would be. This serves only to make the answers slightly more conservative (i.e., higher energy deposition) since some scattering will occur there. However, the effect should be quite small.

In looking at this figure, we see some of the difficulties in trying to calculate analytically the energy deposition in the BPM from a beam striking somewhere upstream. First, on the average, the core of the shower will follow the straight line beam direction. Thus, the beam must be 'pointing' toward the BPM in order to deposit substantial amounts of energy there, and even then the stochastic nature of shower events occurring in the upstream beam pipe might keep it from happening on an event-by-event basis. Second, if the angle is shallow (i.e., a few milliradians), the beam will traverse a greater path length in the aluminum beam pipe before escaping. Also, this places the beam entrance point (O) further from the BPM (P). When multiple scattering and other processes are considered, it is difficult to predict analytically exactly what the shower will look like when, or if, it finally arrives at the BPM. Conversely, as the angle of incidence increases, the path through the beam pipe is shorter (the shower isn't as fully developed), and the beam entrance point is closer to the BPM.

Figure 2 is a graphical representation of this. There are two curves in this figure; the top is the total distance (in cm) from the beam entrance point to the front face of the BPM (labeled OP) as a function of angle, while the lower is the total number of radiation lengths already traversed by

* Angles suggested by J. Murray of the Beam Dynamics Task Force.

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the shower prior to entering the BPM ($0.4 + 0.674$, where 0.674 is the number of radiation lengths in the Al/Fe coupler plus the Fe near the BPM). From this figure, we can see that as the angle decreases, the distance from the BPM increases and the radiation lengths already traversed by the shower increase, and conversely as the angle increases, these quantities decrease.

EGS CALCULATIONS.

The EGS user code, UCSLOPM1, was written for this particular geometry. EGS4 was run without leading particle biasing in order to generate charged particle track pictures, and with leading particle biasing to generate energy deposition values. In the simulation, the beam entrance point (O) on the beam pipe was chosen such that the beam was 'aimed' directly at the front face center (P) of the BPM. Figure 3 shows typical EGS showers (charged particles only) for different angles of incidence, and for a single incident electron. (In this figure, the beam pipe is shown closer to the BPM in order to get everything on one page. In actuality, the shallower angles are moved far to the left of the BPM. For example, the beam entrance point for the 1 mradian angle is 227 cm from the face of the BPM).

In Fig. 3, we see that at very small angles (i.e., 1 mradian), only a few charged particles ever reach the BPM and, correspondingly, the shower is more developed in the Al beam pipe far upstream. At 3 mradians, there are considerable charged particle tracks in the BPM, but no clearly defined high-density core. That is, the charged particles are almost uniformly distributed throughout the BPM and the shower development in the Al beam pipe is less than before. At 10 mradians, there is very little shower development in the beam pipe, and a clearly defined high-density core of charged particles can be seen in the BPM itself. Finally, at 30 mradians, the shower core only partially develops in the BP before escaping altogether.

For energy deposition studies in the BPM, the incident beam was given a Gaussian spread ($\sigma = 50\mu$) with the beam center 'aimed' at the BPM. Actual beam sizes vary with the beta function and eta function in the arcs. 50μ is therefore a pessimistic case. Radial bins in the BPM were chosen relative to the incident beam axis with sizes dictated by statistical considerations. Energy deposition was followed every 0.25 r.l. in the BPM, converted to temperature for 5×10^{10} electrons per pulse, and the maximum temperature then plotted in Fig. 4 as a function of incident angle (in milliradians).

Finally, Fig. 5 shows the fraction of the total incident energy that is deposited in the BPM as a function of angle. We see that this peaks between 5 and 10 mradians at about 5%. In both Figs. 4 and 5, the error bars were obtained from batch statistics of five separate shower runs of between 20,000 and 50,000 events each.

From these last two figures, we see that for realistic angles of incidence (i.e., between 2 and 4 mradians), the temperature rises will be somewhere between 12 and 120° C/pulse with corresponding total energy deposition fractions of about 1.1 and 3.8% (which is of importance in the steady-state temperature case).

REFERENCES

1. W. R. Nelson and T. M. Jenkins, "Temperature Rise Calculations for the Beam Pipe in the SLC Arcs", CN-235, 1983
2. W. R. Nelson and T. M. Jenkins, "Temperature Rise in the Lamberts Septum Magnet Associated with the Positron Target", CN-262, 1984

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

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