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Calculation of Eddy Currents in the Beam Tube

G. Morgan

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Collider Accelerator Department
Brookhaven National Laboratory

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CALCULATION OF EDDY CURRENTS IN THE BEAM TUBE

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G. Morgan and S. Kahn

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*HIGH ENERGY FACILITIES
Brookhaven National Laboratory
Upton, N.Y. 11973*

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PE2D, a saturable-iron 2D program was used to calculate the fields due to eddy currents in the beam tube shown in Fig. 1, which has a vertical outer half-height of 1.5 inch, a horizontal outer half-width of 3.25 inch and a wall thickness of 1.5 mm. The arc has a centerline radius of 7.387 inch and the half-height of the side wall is 0.75 inch. The magnet iron has the configuration shown in Fig II-5 of the Conceptual Design Report, vol. 1 (April 1985). The beam tube material was assumed to be 304L stainless steel, with a resistivity of 0.809×10^{-6} ohm-meter at 100°C .

The eddy current density is given by $j = x \dot{B}_y / \rho$, where x is distance from the center. This continuous distribution was piecewise approximated by dividing the circular segment into four and one-half parts of constant current density with centers at $x=0, .746, 1.485, 2.209,$ and 2.910 inch; the position of the right side is $x = 3.220$ inch. The area of the 4 equal segments is 28.37 mm^2 and of the side is 27.45 mm^2 .

The \dot{B}_y assumed is $(0.4-0.15)/.05 = 5 \text{ T/sec}$, with injection at 0.156 T , or 1.2 msec after field reversal. The j for the 5 segments is $0.117, .233, .347, .457,$ and $.505 \text{ A/mm}^2$, respectively, for a total current per quadrant of 46.61 A . The dissipation per unit length is $\Sigma I^2 \rho / A = 14.79 \text{ W/quadrant}$ or 59.16 W/m for the whole tube, assuming 100% duty cycle.

The computer run was made with a total current of 32.06 A . The field plot in gauss on the median plane for this run is shown in Fig. 2, where the dimensions are in cm; the beam tube horizontal half-width is 8.105 cm .

The Fourier expansion of the field in gauss at 1 cm , corrected to 46.61 A , relative to -1560 G is given in Table 1.

Table 1

$$0.78 \times 10^{-4} \quad 2.4 \times 10^{-7} \quad -1.6 \times 10^{-9}$$

Table 2 lists B_y as a function of position in cm, corrected to 46.61 A .

Table 2

x	0	1	2	3	4	5	6	7
B_y	13.53	13.41	13.05	12.46	11.67	10.71	9.65	8.68

The stored energy in the magnetic field, when the applied field reaches zero, is $7.12 \times 10^{-3} \text{ J/m}$; this implies a time constant for the induced currents of 0.241 msec . The field change at reversal is 27 G ; the time required for this transient to damp to 10^{-4} of the injection field is 1.24 msec .

The current and dissipation scale as \dot{B}/ρ and \dot{B}^2/ρ ,

respectively. If a peak field of 8 kG is assumed, $\dot{B} = 13$ T/sec, so the induced field is 35.1 G, $b_2 = 2.5 \times 10^{-4}$, and the dissipation (100% duty cycle) is 606 W/m; since the field change is 3.2 times as large, an additional 0.28 msec should be allowed for damping. A more resistive beam tube material would reduce these numbers. The best material for the purpose would be a titanium alloy such as Ti-6Al-4V which has a resistivity of $1.756 \mu\Omega\text{m}$ at 100°C , 2.2 times that of 304L ss. Differences in strength of the material are not very important, since the buckling strength increases as the cube of the thickness.