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Calculation of Eddy Currents in the Beam Tube

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CALCULATION OF EDDY CURRENTS IN THE BEAM TUBE

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PE2D, a saturable-iron 2D program was used to calculate the fields due to eddy curents 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 $0.809\text{x}10^{-6}$ 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 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 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 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

b_2	b_4	b_6
$0.78\text{x}10^{-4}$	$2.4\text{x}10^{-7}$	$-1.6\text{x}10^{-9}$

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 $7.12\text{x}10^{-3}$ 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 $\dot{B}/\rho$ and $\dot{B}^2/\rho$, respectively. If a peak field of 8 kG is assumed, $\dot{B} = 13$ T/sec, so the induced field is 35.1 G, $b_2 = 2.5\times10^{-4}$, 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 $\mu\Omega$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.