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Specifications for the Extraction Kicker TiN Coating

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Due to concerns about electron cloud buildup it was decided to coat the extraction kicker ferrites with Titanium Nitride (TiN) [1]. Since TiN is a fair conductor of electricity a mask was applied to the ferrite before coating. This resulted in a coating composed of rectangular cells of length $a = 5$ cm and width $b = 1$ cm. The cells are spaced by $h = 0.1$ cm at each face. The mask is not perfect so there is a finite resistance between the cells. The question at hand is to estimate the effect of this cell to cell resistance on the kicker properties.

The TiN coating within a cell is about $\ell_0 = 100$ nm thick , and the minimum measured cell to cell resistance is $R_0 = 100\ \Omega$. There are many parallel paths the current may take, but the worst average case corresponds to the current being confined to a single 1 cm edge. With a distance between cells of 0.1 cm the product of the conductivity and thickness of the film between the cells yields a surface impedance of $Z_{s,2} = 1/\sigma\ell = R_0 b/h = 1$ kΩ. For 100 nm of TiN, the surface impedance within the cells is $Z_{s,1} = 1/\sigma\ell = 2.5\Omega$.

To derive the effects of eddy currents in the film let the pole face of the magnet lie in the $x\times z$ plane. Consider only the y component of the magnetic field and approximate the induction equation by $\nabla\times\mathbf{H} = \mathbf{J}$ [2]. Assume the permeability of the ferrite is very large and integrate the induction equation along y, across the magnet gap of length g. The effective surface current density is

$$\mu_0 K_x/g = \frac{\partial B_y}{\partial z}, \qquad \text{and} \qquad \mu_0 K_z/g = -\frac{\partial B_y}{\partial x}, \tag{1}$$

where B_y is the average vertical magnetic field. At boundaries between materials the normal component of the surface current density ($\mathbf{K}$)is continuous. The electric field is related to the surface current by $\mathbf{K} = \sigma\ell\mathbf{E}$ and the tangential component of the electric field must be continuous across material boundaries. Combining (1) with Faraday's Law yields.

$$\frac{\partial^2 B_y}{\partial x^2} + \frac{\partial^2 B_y}{\partial z^2} = \frac{\mu_0\sigma\ell}{g}\frac{\partial B_y}{\partial t} \tag{2}$$

For $R_0 \to \infty$, $B_z = 0$ at the edge of the cell. Suppose that the field in the absence of eddy currents is given by a spatially uniform $B_0(t)$. When eddy currents are included the field is

$$B(x,z,t) = \int_0^\infty dt_1 B_0(t-t_1) \sum_{k,m} a_{k,m} B_{k,m}(x,z) \exp(-t_1/\tau_{k,m}) \tag{3}$$

The field and current loops for the mode with the largest $\tau_{k,m}$ are shown in Figure 1. The coefficients $a_{k,m}$ are chosen so that for constant B_0, $B(x,z,t\to\infty) = B_0$.

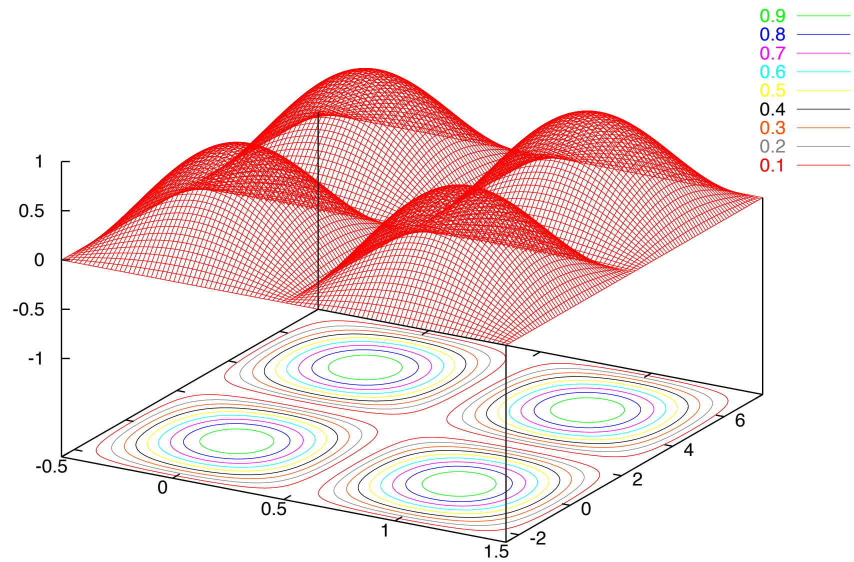

Figure 1: The surface shows the eddy current magnetic field for $B_{1,1}(x,z)$ while the contours show the closed eddy current loops for infinite cell to cell resistance

With a finite R_0, eddy currents can flow between cells. Assume the cells are aligned with their long axis along z and set the length along z to be equal to the length of the magnet ($L = 40$ cm). The region near $x = 0$ is shown in Figure 2. To calculate the eigenmodes of (2) set $B_y(x,z,t) = \sin(kz\pi/L)B(x)\exp(-t/\tau)$. There are about 20 stripes so approximate the system as periodic in x. A single period lies in the interval $-(b+h)/2 < x < (b+h)/2$. For $|x| < b/2$ the surface impedance is Z_1 and it is Z_2 for $b/2 < |x| < (b+h)/2$. The lowest lying eigenmode will have no zeroes so

$$B(x) = \begin{cases} \cos(\lambda_1 x) & |x| < b/2, \\ A\cosh(\lambda_2[|x| - (b+h)/2]) & b/2 < |x| < (b+h)/2 \end{cases} \tag{4}$$

The boundary conditions between slices require $B(x)$ and $Z_s dB/dx$ to be continuous.

$$\cos(\lambda_1 b/2) = A\cosh(\lambda_2 h/2), \tag{5}$$

$$Z_{s,1}\lambda_1 \sin(\lambda_1 b/2) = Z_{s,2}\lambda_2 A \sinh(\lambda_2 h/2) \tag{6}$$

Both regions have the same time dependence so there is another constraint

$$Z_{s,1}[(\pi/L)^2 + \lambda_1^2] = Z_{s,2}[(\pi/L)^2 - \lambda_2^2] = \mu_0/(g\tau).$$

The set of equations above requires numerical solution. For our case, $Z_{s,1} = 2.5\Omega$, $Z_{s,2} = 1000\Omega$, $L = 40$ cm, $b = 1$cm, and $h = 0.1$ cm. The change in τ between $Z_{s,2} = 1000\Omega$ and $Z_{s,2} = \infty$, for the lowest lying mode, is less than 1%. The decay time for the slowest mode is 1.3 ns.

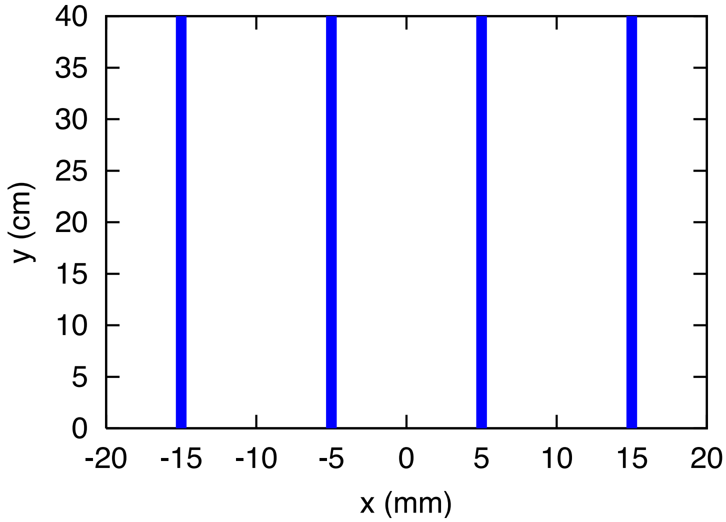

Figure 2: Figure showing the geometry used to estimate the effect of the cell to cell resistance. The white region has a surface impedance of $Z_{s,1} = 2.5\Omega$ and the blue region has a surface impedance of $Z_{s,2} = 1\ \mathrm{k}\Omega$

References

[1] A. Aleksandrov, unpublished note.

[2] P.J. Bryant, CERN 92-05 (1992). Available online at http://preprints.cern.ch/cernrep/