

Specifications for the Extraction Kicker TiN Coating

M. Blaskiewicz

April 2004

Collider Accelerator Department
Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



Specifications for the extraction kicker TiN coating

BNL/SNS TECHNICAL NOTE

NO. 134

M. Blaskiewicz, Brookhaven National Laboratory

April 30, 2004

COLLIDER-ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Specifications for the extraction kicker TiN coating

M. Blaskiewicz, C-AD Brookhaven National Laboratory

April 30, 2004

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 $Z_{s,2} = 1/\sigma\ell = R_0 b/h = 1 \text{ k}\Omega$. 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

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

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.

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

For $R_0 \rightarrow \infty$, $B_z = 0$ 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

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

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 , $B(x, z, t \rightarrow \infty) = B_0$.

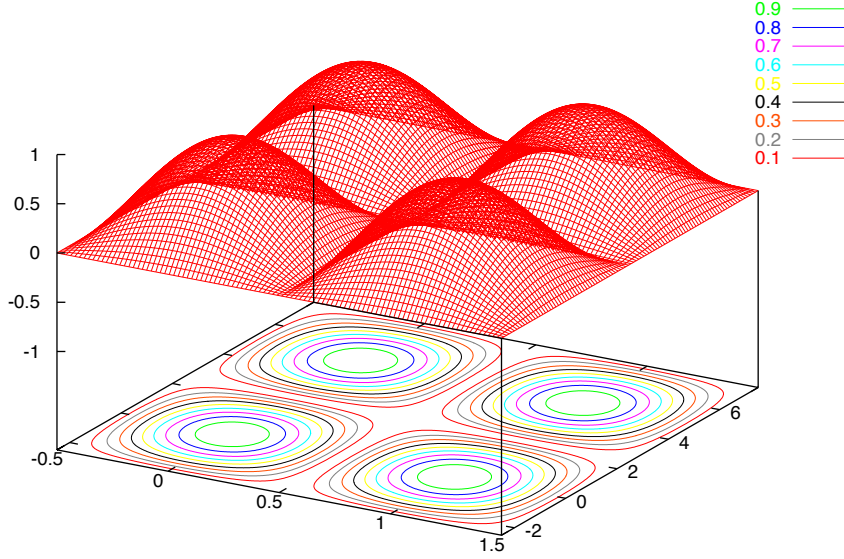


Figure 1: The surface shows the eddy current magnetic field for $B_{1,1}(x, z)$ while the contours show the closed eddy current loops for infinite cell to cell resistance

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

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

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

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

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

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.

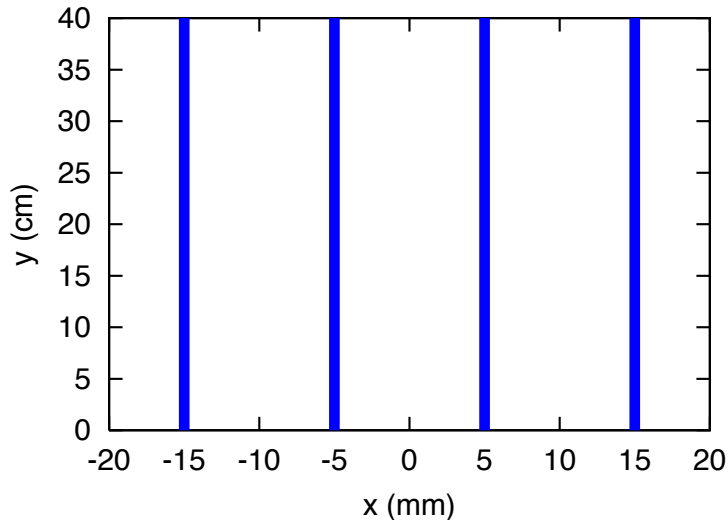


Figure 2: Figure showing the geometry used to estimate the effect of the cell to cell resistance. The white region has a surface impedance of $Z_{s,1} = 2.5\Omega$ and the blue region has a surface impedance of $Z_{s,2} = 1 \text{ k}\Omega$

References

- [1] A. Aleksandrov, unpublished note.
- [2] P.J. Bryant, CERN 92-05 (1992). Available online at <http://preprints.cern.ch/cernrep/>