Calculation No: NSTXU-CALC-11-24-00 **Revision No:0**

Title Eddy Current Calculations for OBD12 Tiles

Purpose of Calculation: (Define why the calculation is being performed.)
This calculation addresses two concerns about induced currents in the OBD12 tile structure: the effect of the hold down rods acting as a loop, and the tile having its castellation slots completely shorted out by lithium – the latter highly conservative and unlikely

Codes and versions: (List all codes, if any, used)
Hand Calculations

References (List any source of design information including computer program titles and revision levels.)
Report PPPL-2158 Bialek et al.
Drawing E-ED1408 Row 1 and 2 Outboard Divertor Tiles Assembly and Detaile

Assumptions (Identify all assumptions made as part of this calculation.)
Assume fully developed resistive solution. Use the dB/dt from Art Brooks's spreadsheet of August 2017, and assume it is all normal to the tile. Assume that the tile behaves as a plate normal to the changing flux, and that this plate can be treated as a loop as in PPPL-2158. Assume that the rods, and their conducting path through the structure, form a loop whose resistance is due to the rods only.

Calculation (Calculation is either documented here or attached)
Calculate the area that is penetrated by the flux change. The voltage on an equivalent loop is the product of dB/dt and the area. Details are on the following pages.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)
The forces and moments due to eddy currents in the rods, and in a fully shorted tile, are well within the allowable stresses on the structure and mounting screws. A fully shorted tile is highly unlikely.

Cognizant Individual (or designee) printed name, signature, and date
Robert Ellis

Robert Ellis Digitally signed by Robert Ellis Date: 2018.09.24 09:49:11 -04'00'

Preparer's printed name, signature and date
Robert Ellis

Robert Ellis Digitally signed by Robert Ellis Date: 2018.09.24 09:49:33 -04'00'

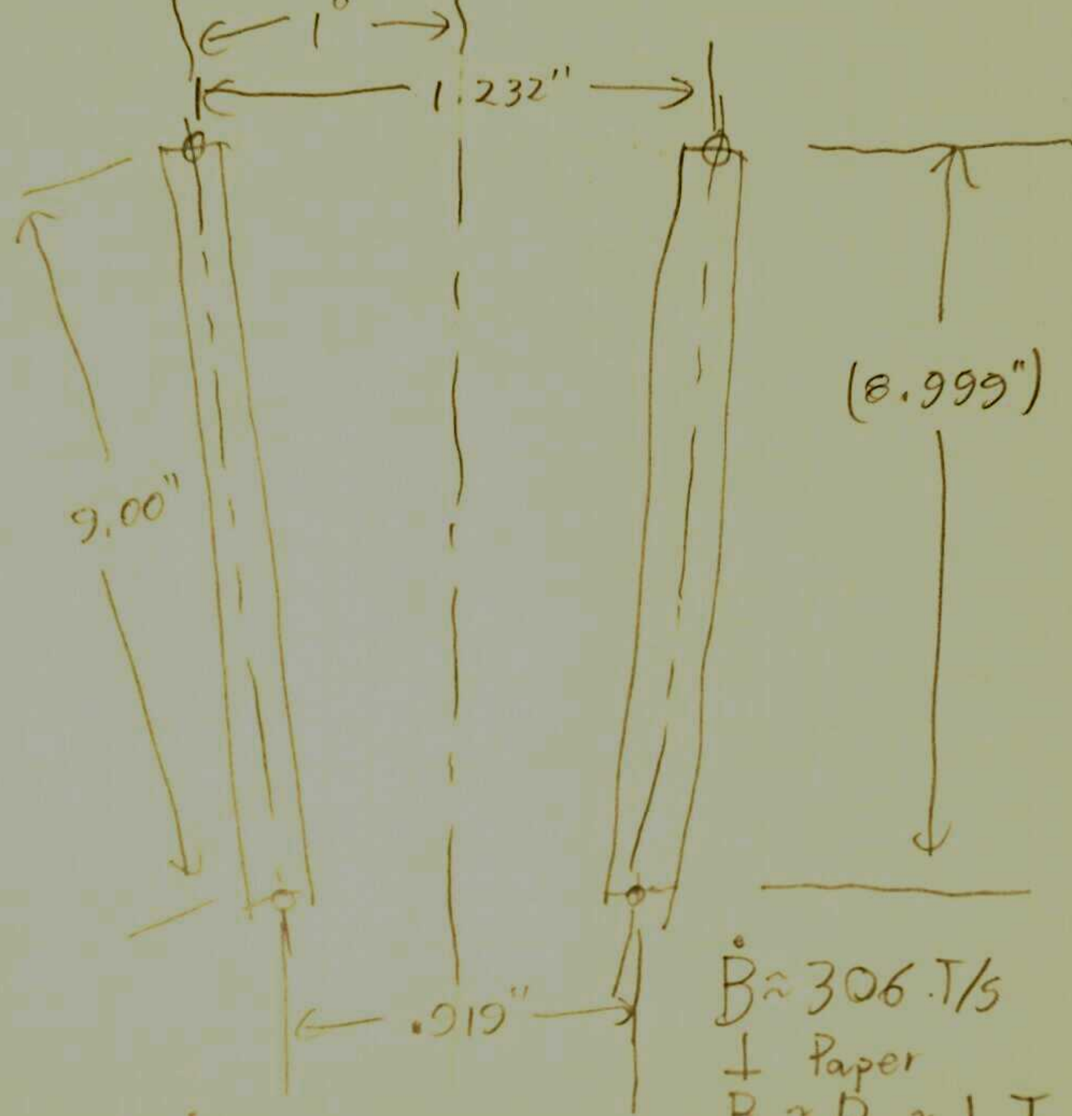
I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Art Brooks Art Brooks Digitally signed by Art Brooks Date: 2018.09.27 13:16:41 -04'00'

No. EC01 DATE 09.18.18

Induced Currents in Hold Down Rods



$\dot{B} \approx 306$ T/s
$\perp$ Paper
$B_p \approx B_T \approx 1$ T

Area $\perp \dot{B}$

$$A_{\Phi} = \frac{8.999}{2}(.919 + 1.232) = 9.678 \text{ in}^2 = 6.24 \times 10^{-3} \text{ m}^2$$

(trapezoid)

SHOT NOTE

No. EC02 DATE 09.18.18

Length of conducting loop is 18.0" = .457 m = l

(neglect all other resistance)

a = Cross section area of rod is $\frac{\pi(.375^2)}{4} = .110 \text{ in}^2 = 7.13\times10^{-5} \text{ m}^2$

then $l/a = \frac{.457 \text{ m}}{7.13\times10^{-5} \text{ m}^2} = 6.41\times10^{3} \text{ m}^{-1}$

Loop resistance $R = \rho\, l/a$, where $\rho = 7\times10^{-7}\ \Omega\text{-m}$

$R = 7\times10^{-7}(6.41\times10^{3}) = 4.49\ \text{m}\Omega$

From Art Brooks Spreadsheet "20170818 Halo Forces"

$\dot{B} \approx 306\ \text{T/s} \Rightarrow \dot{\Phi} = 306\ \text{T/s}(6.24\times10^{-3}\ \text{m}^2) = 1.91\text{V}$

$I_{loop} = \frac{\dot{\Phi}}{R} = \frac{1.91\text{V}}{4.49\ \text{m}\Omega} = 425\text{A}$ Fully developed resistive solution

On each rod, $F = I(l)(B) = 425\text{A}\left(\frac{9"}{39.37}\right)(1\text{T}) = 97.2\text{N}$

$97.2\text{N} = 21.9$ lbf

We have 4 screws securing each rod. #8-32

Tensile Stress Area = $4(.0140 \text{ in}^2) = .056 \text{ in}^2$

$\Rightarrow \sigma \approx 21.9 \text{ lbf}/.056 \text{ in}^2 = 391$ psi

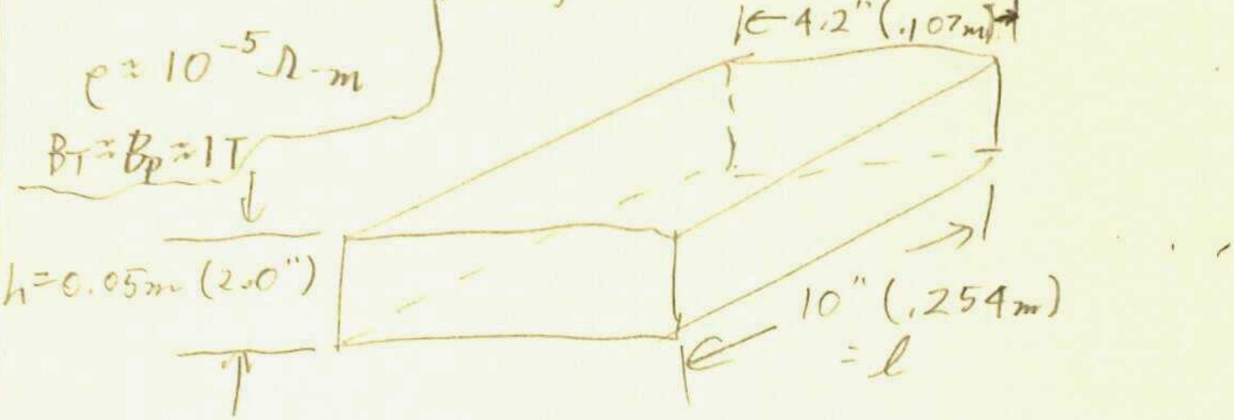
Conclusion: No worries here

Refs: E-ED1408 Rev 0, Machinery's Handbook

No. EC03 DATE 09.18.18

Induced Currents in Shorted Tile

- Model tile as a brick that encloses trapezoidal tile
- Apply fully developed resistive solution based on PPPL-2158.
- Ref. E-ED1408 Rev. 0, PPPL-2158



Loop resistance

$$R = \frac{3.33\rho(\ell^2+w^2)}{h\ell w} = \frac{3.33(10^{-5})(.254^2+.107^2)}{.05(.254)(.107)} = 1.86\ m\Omega$$

$\dot{B} \approx 306\ T/s$ from "20170818 Halo Forces"

From PPPL-2158

Effective area for calculating flux is $.433\ell w$

$$A = .433(.254)(.107) = 1.18\times10^{-2}\ m^2$$

$$\therefore \dot{\Phi} = 306\ T/s\ (1.18\times10^{-2}\ m^2) = 3.61\ V \text{ and } I = \frac{3.61}{.00186\ \Omega} = 194$$

$$I = \frac{3.61V}{1.86\ m\Omega} = 1.94\times10^3 A$$

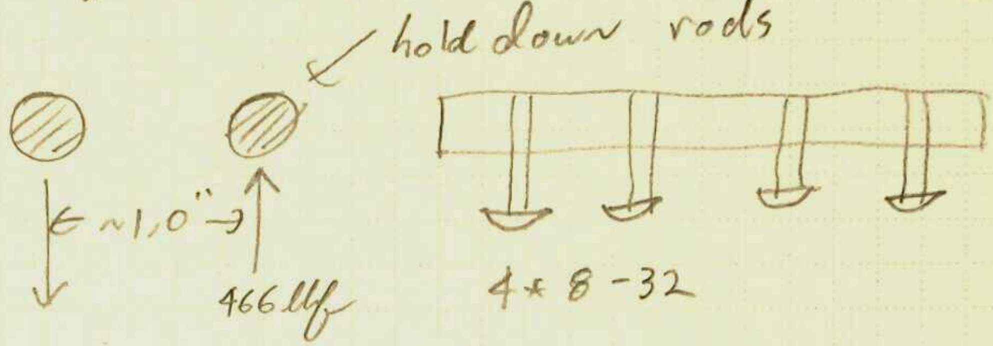
Moment on brick is $I\ell wB = 1.94\times10^3(.254)(.107)(1)$

$= 52.7\ N\text{-}m = 466.\ in\text{-}lb_f$

SHOT NOTE

No. EC04 DATE 09.18.18

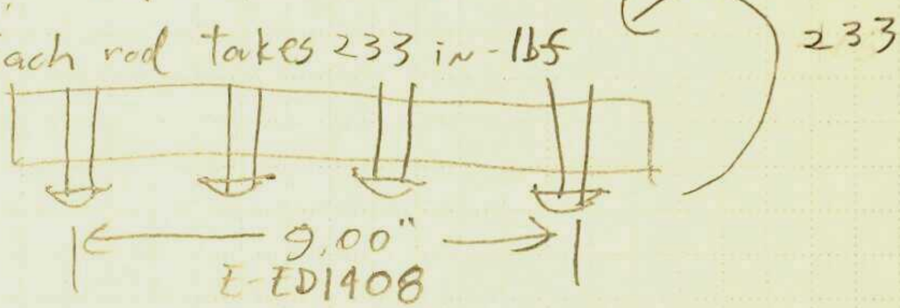
Consider $M_r = 466$ in-lbf



$\frac{466}{4} = 117$ lbf/screw $\Rightarrow \sigma = \frac{117}{.014 \text{ in}^2} = 8.3$ ksi

Consider $M_T = 466$ in-lbf

Each rod takes 233 in-lbf



$\frac{233 \text{ in-lbf}}{9"} = 25.9$ lbf in outside screws

1.9 ksi

117 lbf + 26 lbf = 143 lbf $\Rightarrow$ 10.2 ksi

Not a problem, even with preload added.

SHOT NOTE