Calculation No: <u>NSTXU-CALC-11-28-00</u> # Revision No: <u>0</u>

Calculation of CSA tile Heat flux enhancement and fish scale angle

Purpose of Calculation: (Define why the calculation is being performed.)

- 1) To calculate Heat-flux enhancement due to tile to tile offset, in plasma facing direction, during installation.
- 2) To calculate the fish-scale angle which reduce the heat flux enhancement.

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

References (List any source of design information including computer program titles and revision levels.)

PDR presentation from A.Brooks. "Engineering loads and boundary conditions for PFC"

Assumptions (Identify all assumptions made as part of this calculation.)

Due to installation and assembly tolerances the tile to tile offset(in plasma facing direction) can be .010" to .03". To be conservative in this calculation .06" is used to account for any unknowns.

Calculation (Calculation is either documented here or attached)

See attached.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

A heat flux enhancement factor of 1.17 @ 3.3" width is found for 0.060" tile offsets. The chamfer heat flux enhancement is found to be 1.58.

Cognizant Individual (or designee) printed name, signature, and date Ankita Jariwala

Preparer's printed name, signature and date Ankita Jariwala

Ankita Jariwala Digitally signed by Ankita Jariwala Date: 2018.09.28 05:59:35 -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

Michael Jaworski

Revised 9/10/18





National Spherical Torus eXperiment - Upgrade

NSTX-U

Calculation of CSA tile Heat flux enhancement and fish scale angle

NSTXU-CALC-11-28-00

Date Sept.14th 2018

Ankita Jariwala Date: 2018.09.28 05:59:04 -04'00'

> Prepared By Ankita Jariwala Michael Digitally signed by Michael Jaworski Jaworski Date: 2018.09.28 02:29:41 -04'00'

Checked By M.Jaworski

Robert Digitally signed by Robert Ellis Date: 2018.09.28 10:56:48-04'00'

Approved By – Technical Authority (Mechanical) R. Ellis

NSTX-U CALCULATION

Record of Changes

| Rev. | Date | Description of Changes | Revised by | | |
|------|---------|------------------------|------------|--|--|
| 0 | 9/14/18 | Initial Release | | | |
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Calculation:

| CSAS | Case # -> | 1 | 2 | |
|----------------------|-------------------|--|---|--|
| Max Angle | degrees | 9.2 | 12 | |
| Min Angle | degrees | 7.3 | 9.5 | |
| Extent | cm | 8 | 8 | |
| Range of Application | m | Z > 1.1 | Z > 1.1 | |
| Heat Flux | MW/m ² | 5.2 | 3.6 | |
| Duration | sec | 2.0 | 2.0 | |
| Reference Scenario | | High I _P /B _T LSN L-Mode, 3 MW | High I _P /B _T LSN L-Mode, 2 MW | |

 Table 1 Heat flux requirement for the CSAS (Ref. PFCs SRD <u>NSTX-U-RQMT-SRD-</u>003-00)

Calculation formula used as defined in PFC load presentation at PDR.

Heat Flux Enhancement Evaluation From Field Errors – Preliminary Assessment

- Fields from Each PF coil are calculated at PFC locations
 - Coil geometry and max coil current magnitude based on Design Point Spreadsheet
 NSTX_CS_Upgrade_120409.xls
 - Fields calculated first at nominal location and then at 1 mm lateral offset (ie horizontal displacement of coil axis). Error field given as difference in two values
 - Analysis done with PPP/EAD's Magnetics Library of FORTRAN Codes
- Impact on Tile Heating from change in field angle estimated from field error
 - Angle change estimated as $\delta \alpha = \frac{\delta B_{pf}}{B_{tf}}$
 - Fishscaling of each tile calculated as $\beta = \frac{1}{2} \frac{1}{10} \frac{$
 - tol = vertical alignment tolerance of tiles/modules
 - gap = gap between tiles/modules
 - w_{tile} = width of tile/module
 - α_{max} = max flux impingement from PFC requirements
 - Heat Flux Enhancement Factor from fishscaling given as $EF_{fs} = sin(\alpha_{min} + \beta)/sin(\alpha_{min})$
 - Total Heat Flux Enhancement Factor calculated as <u>EF_{tot}=sin(α_{min}+β+δβ)/sin(α_{min})</u>
 Assumes heat flux parallel to field line does not change with field error
 - Heat Flux attributed to field error is EF_{tot}/EF_{fs}



| CSA Tile Fishscale Angle and Effective Heat Load Calculation for Tile to Tile offset of .06" and 5.2 MW | | | | | β=atan((to | l+gap*tar | n(a _{max}))/w _{tile}) | EF=sir | $EF=sin(\alpha_{min}+\beta)/sin(\alpha_{min})$ | | |
|--|-----------------------------|---|--------------------------------------|--------------------------------------|------------------------------|---|---|---------------------------------|---|--|--|
| W (tileWidth) | g(Gap between tiles) | t (tile to tile vertical offset) | impingment Angle α _{max} | impingment Angle α _{min} | Fishscale Angle Beta β | Fishscale Angle Beta in Deg | Enhancement Factor EF | Effective heat load MW/m2 | D (Height of fishscale gemotery)= w*tan(Beta) = tol+ Gap*tan(Inc . Angle) | | |
| 5.5 | 0.063 | 0.06 | 12 | 7.3 | 0.013 | 0.76 | 1.10 | 5.740 | 0.073 | | |
| 5 | 0.063 | 0.06 | 12 | 7.3 | 0.015 | 0.84 | 1.11 | 5.794 | 0.073 | | |
| 4.5 | 0.063 | 0.06 | 12 | 7.3 | 0.016 | 0.93 | 1.13 | 5.860 | 0.073 | | |
| 4 | 0.063 | 0.06 | 12 | 7.3 | 0.018 | 1.05 | 1.14 | 5.943 | 0.073 | | |
| 3.5 | 0.063 | 0.06 | 12 | 7.3 | 0.021 | 1.20 | 1.16 | 6.049 | 0.073 | | |
| 3.3 | 0.063 | 0.06 | 12 | 7.3 | 0.022 | 1.27 | 1.17 | 6.100 | 0.073 | | |
| 2.5 | 0.063 | 0.06 | 12 | 7.3 | 0.029 | 1.68 | 1.23 | 6.387 | 0.073 | | |
| 3.92 | 0.063 | 0.06 | 12 | 7.3 | 0.019 | 1.07 | 1.15 | 5.958 | 0.073 | | |
| | CSA Ti | le Fishso | ale Angle | and Effect | tive Heat l | oad Cal | culation fo | <u>r Tile hole</u> | chamfer | | |
| Chamfer Angle θ (chamfer+ fishscale angle) | | mfer eθ(nfer+ I scale r e) α | mpingme nt Angle xmin | F=sin(α | _{min} +θ)/si | in(α _{mir} | Effective heat load MW/m2 | | | | |
| For Hole Chamfer | e r | 4.27 | 7.3 | 1 | .58 | | 8.207935 | 309 | | | |
| Lower the impingment angle (α) higher the EF/ Effective heat load) Smaller Tile width/chamfer width higher the Effective Heat Load | | | | | | | | | | | |

| CSA Tile Fishscale Angle and Effective Heat Load Calculation for Tile to Tile offset of .06" and Heat flux of 3.6MW | | | | | $egin{array}{lllllllll} egin{array}{llllllllll} egin{array}{llllllllllllllllllllllllllllllllllll$ | | | | ו(α _{min}) | |
|---|-------------------|--------------------------------|----------------------|-----------------------|---|-------------------------------|-------------|------------------------|---|--|
| W (tileWidth | g(Gap between | t (tile to tile vertical | impingment | impingment | Fishscale Angle Beta | Fishscale Angle Beta in | Enhancemen | Effective heat load | D (Height of fishscale gemotery)= w*tan(Beta) = tol+ Gap*tan(Inc | |
|) | tiles) | offset) | Angle α_{max} | Angle α_{\min} | β | Deg | t Factor EF | MW/m2 | . Angle) | |
| 5.5 | 0.063 | 0.06 | 12 | 7.3 | 0.013 | 0.76 | 1.10 | 3.974 | 0.073 | |
| 5 | 0.063 | 0.06 | 12 | 7.3 | 0.015 | 0.84 | 1.11 | 4.011 | 0.073 | |
| 4.5 | 0.063 | 0.06 | 12 | 7.3 | 0.016 | 0.93 | 1.13 | 4.057 | 0.073 | |
| 4 | 0.063 | 0.06 | 12 | 7.3 | 0.018 | 1.05 | 1.14 | 4.114 | 0.073 | |
| 3.5 | 0.063 | 0.06 | 12 | 7.3 | 0.021 | 1.20 | 1.16 | 4.188 | 0.073 | |
| 3.3 | 0.063 | 0.06 | 12 | 7.3 | 0.022 | 1.27 | 1.17 | 4.223 | 0.073 | |
| 2.5 | 0.063 | 0.06 | 12 | 7.3 | 0.029 | 1.68 | 1.23 | 4.422 | 0.073 | |
| 3.92 | 0.063 | 0.06 | 12 | 7.3 | 0.019 | 1.07 | 1.15 | 4.125 | 0.073 | |

Conclusion:

The CSA tiles were analyzed with this heat fluxes. Analysis results show that these tiles can handle higher the heat loads and the stresses are under allowable. Analysis report is filed here.

Structural analysis of Center Stack Angular Section (CSA) tiles. **NSTXU-CALC-11-21-00**