1 Checks for Calculation No: NSTXU-CALC-11-28-00
Revision No: 00

Calculation of CSA tile Heat flux enhancement and fish scale angle

Component was checked against latest design
Yes

All required load cases are included and current
SRD cited is rev 00. Current revision is NSTX-U-RQMT-SRD-003-02. Table 4.5-1 specifying load cases for CSAS has not changed between revisions.

Discuss method used in the calculation
The calculation makes use of analytic formulations developed by A. Brooks for the HHF PDR. The changing arc-length of the tile creates a varying heat flux enhancement factor since the tile design features a constant step-height along its length.

Discuss how the calculation was checked (*)

Calculation will be checked with spot-checks on the calculation and directionality in the drawings at present.

See below.

List issue identified and how they were resolved
Issue with step-heights: the original calculation assumed a step-height of 0.060" from tile-to-tile. Drawings indicate the step height is 0.073. This can be verified with individual tile dimensions (E-ED1421 and E-ED1422) or with the assembly drawing (E-ED1459). However, enhancement factors calculated are still similar and this is the basis of further calculations.

Tolerance stack-up shows the fish-scale step could be reduced to as little as 0.041", but the metrology report was not available in time to propagate this information to the design.

No issues are found in the directionality of the fish-scale features. The drawings match the features prescribed in the SRD.

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Technical Authority: Peter H. Titus Digitally signed by Peter H. Titus Date: 2018.09.28 11:34:29 -04'00' (sign and date)

(*) independent calculations can be appended

Calculation checks.

Latest drawings are checked and the following dimensions are found:

CSAS Tiles					
	Dimension	**tolerance**	**DWG**	**Sheet**	**Zone**
Min Width	3.182	0.005	E-ED1422	1	A-5
Max Width	4.515	0.005	E-ED1421	1	I-2
Surf profile	-	0.004	E-ED1422	1	D-3
Step height	0.073	0.004	E-ED1459	1	I-8
Grafoil thickness	0.03	0.002	E-ED1425		
Base Profile	0	0.01	METROLOGY		
Thickness tol.		0.004	E-ED1422	1	D-3
Tile gap	0.061	0.005	E-ED1459	1	J-7
Min Step required	0.041	inch			
Max angle	1.31	degrees			
Min Angle	0.93	degrees			
Min Alpha	7.3	degrees			
Max enhancement	1.18				
Min enhancement	1.13				

Based on the tolerance stack from the base profile (reported in NSTX-U-REC-087-00), a minimum step height needed to eliminate leading edges is 2*0.01+0.004+2*0.002 + gap*sin(alpha) =0.041" (2* base profile tolerance, 1* surface profile tolerance, 2*grafoil thickness tolerance is the "vertical" misstep resulting from manufacturing tolerances).

The drawing nominal step height is directly measured in drawing E-ED1459 and is 0.073" which exceeds the minimum from the tolerance stack-up. The leading edges are shadowed, but the surface angle exceeds the minimum.

The linear widths of the tile are reported from E-ED1422 and E-ED1421 at the thickest and thinnest sections. The effective surface angle is the rise over the run approximating the curve as a straight line. This yields a maximum angle (at the thinnest part of the tile) of 1.31 degrees with respect to a cylindrical surface whose axis is coincident with the CS-casing. The minimum angle is 0.93 degrees.

The enhancement factor is calculated as follows:

$$f_{enh} = \frac{\sin(\alpha+\beta)}{\sin(\alpha)}$$

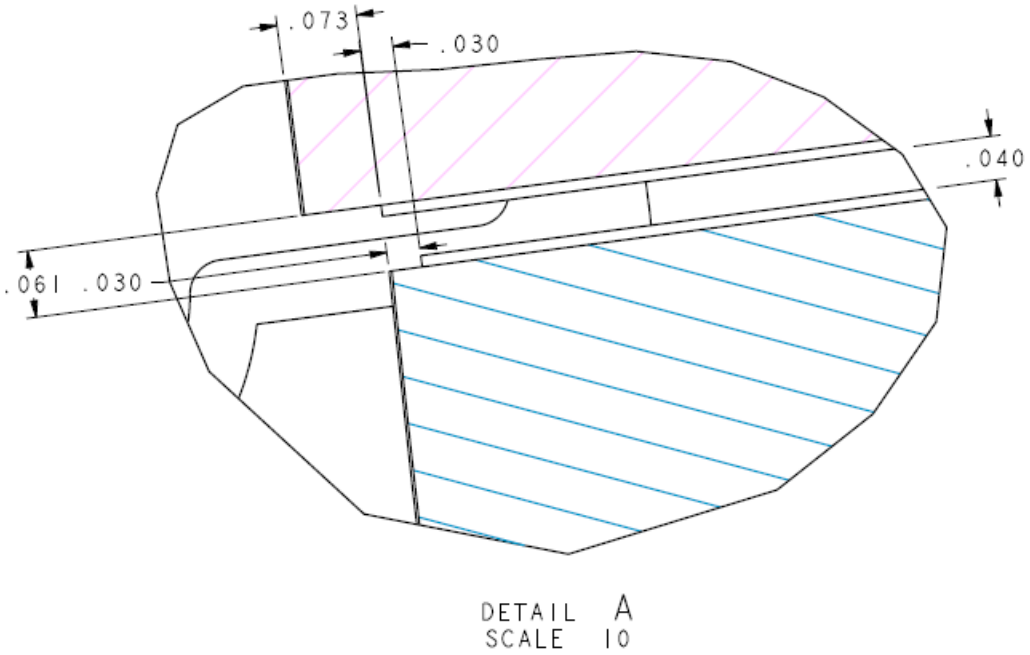
The SRD table gives the minimum alpha as 7.3 degrees. At minimum alpha and maximum beta, the maximum enhancement factor is found to be 1.18 and the minimum is 1.13. This maximum enhancement factor would yield an effective surface heat flux of 6.14 MW/m^2.

These values compare well to the values in the original calculation (1.18 @ 3.2” vs. 1.17 @ 3.3”).

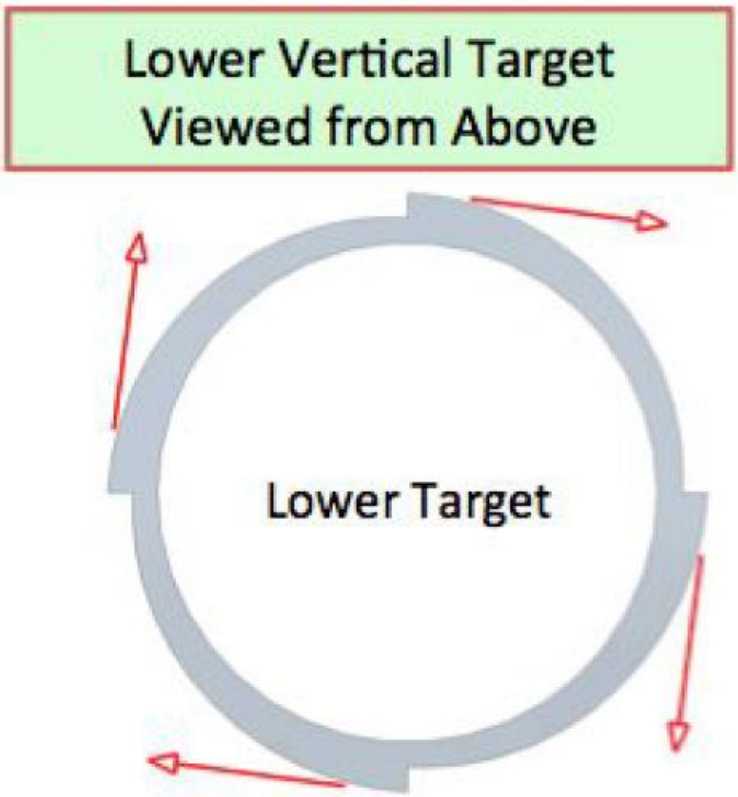
A discrepancy is found in the step height assumed between tiles. The original calculation reports 0.060” whereas the drawings indicate 0.073.

Directionality check

Drawing E-ED1459 gives an assembly with views that can be compared directly with the SRD.



This image is taken from E-ED1459 at zone I-8 showing a section view from above looking downward at the HTP. Moving clockwise, there is a step outward in major radius.



This image is from NSTX-U-RQMT-SRD-003-02 giving the sense of the fish-scale steps. Moving clockwise, there is a step outward in major radius. This sense matches the current drawing.

2 Minimum Requirements for Checking Calculations

1. Assure that inputs were correctly selected and incorporated into the design.

2. Calculation considers, as appropriate:

   - Performance Requirements (capacity, rating, system output)
   - Design Conditions (pressure, temperature, voltage, etc.)
   - Load Conditions (Electromagnetic (Lorentz Force), seismic, wind, thermal, dynamic)
   - Environmental Conditions (radiation zone, hazardous material, etc.)
   - Material Requirements
   - Structural Requirements (foundations, pipe supports, etc.)
   - Hydraulic Requirements (NPSH, pressure drops, etc.)
   - Chemistry Requirements
   - Electrical Requirements (power source, volts, raceway, and insulation)
   - Equipment Reliability (FMEA)
   - Failure Effects on Surrounding Equipment
   - Tolerance Buildup

3. Assumptions necessary to perform the design activity are adequately described and reasonable.

4. An appropriate calculation method was used.

5. The results are reasonable compared to the inputs.

6. Error bars (range) for inputs used, results / conclusions, assumptions, have been considered and are acceptable.

3 NOTE: IT IS THE RESPONSIBILITY OF THE CHECKER TO USE METHODS THAT WILL SUBSTANTIATE TO HIS/HER PROFESSIONAL SATISFACTION THAT THE CALCULATION IS CORRECT.

BY SIGNING CALCULATION, CHECKER ACKNOWLEDGES THAT THE CALCULATION HAS BEEN APPROPRIATELY CHECKED AND THAT THE APPLICABLE ITEMS LISTED ABOVE HAVE BEEN INCLUDED AS PART OF THE CHECK.