PHOTON BEAM APPLIED AS HEAT FLUX ON IRREGULAR SURFACES IN FEA*

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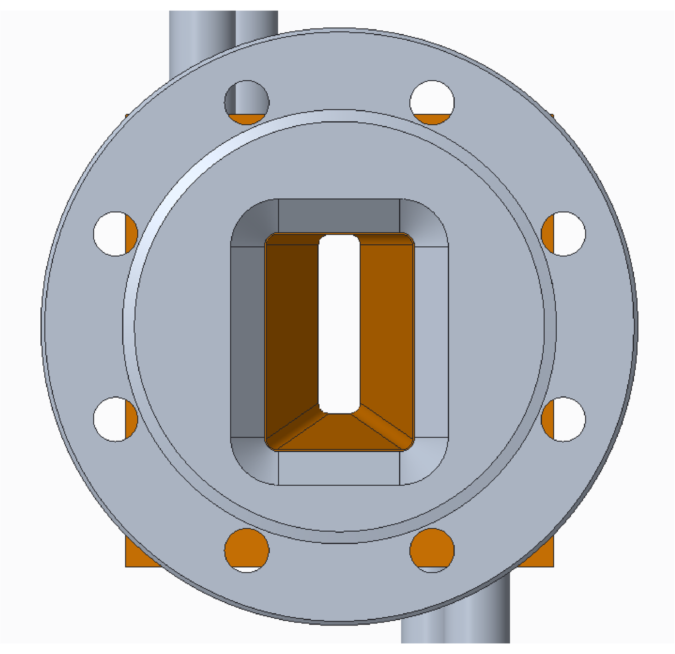
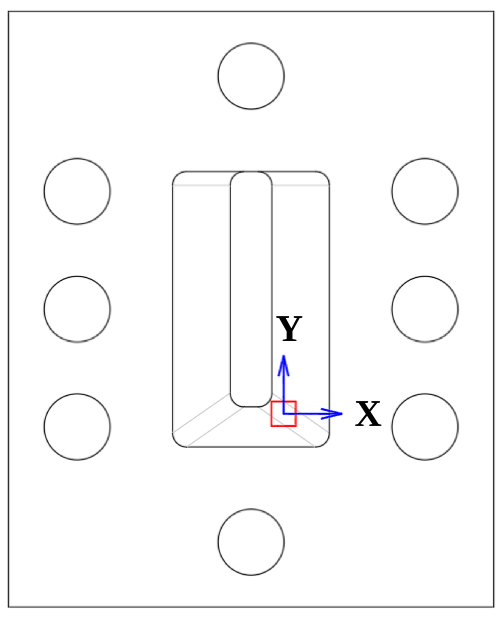
ABSTRACT

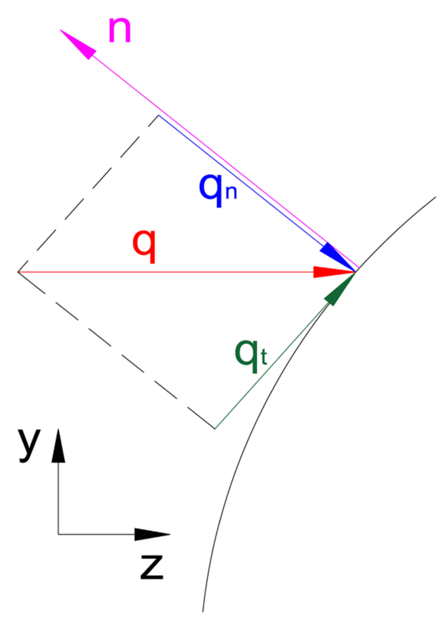
The light source front ends and beamlines contain several devices designed to limit the size of, or completely stop, the photon beam. Most of these devices are meant to protect personnel and/or equipment, thus their failure would have serious implications for the facility operation. The photon beam carries extremely high energy, thus the system will experience very large thermal loads. Accurate temperature and stress distribution of these components, based on well-reasoned assumptions, is needed to accurately review the performance of these devices during the design process. Applying non-uniform heat flux as a thermal load in simulation presents a challenge. This work describes the steps of the thermomechanical numerical simulation for a typical component at the Advanced Photon Source (APS), subject to photon beam interception. The numerical algorithm used to apply the non-uniform heat flux distribution on an irregular type of surface is presented in detail. The algorithm was developed using the commercial Finite Element Analysis (FEA) software ANSYS Workbench of ANSYS, Inc.

PROBLEM FORMULATION

- A typical mask design is the boxed-cone. The beam could be missteered and partially or fully strike the mask [3]. One of the most critical scenarios is when the beam strikes the corner of the mask taper.







- The power density distribution corresponding to the normal beam incidence assuming a 4th order Gaussian equation was calculated using SRUFF [2]:

$$q = \exp(a+bx^2+cy^2+dx^4+fy^4+gx^2y^2)$$

- a=4.3828, b=-0.0373, c=-0.20196, d=-0.00231, f=0.0045228 and g=-0.020031 for a particular loading scenario for demonstration purposes.
- The heat flux flowing into the surface of the body is the normal component of the heat flux, q_n.

$$q_n = -\mathbf{q} \cdot \mathbf{n}$$

- On the corner surface the normal vector varies at each point of the surface. The heat flux at each node of the element has to be applied as a numerical algorithm.

NORMAL VECTORS COMPUTATION [1]

- ANSYS Workbench allows access to element numbers and node coordinates [4]
- The vector product of two adjacent vectors is the normal vector:

$$\mathbf{v15} \times \mathbf{v18} = \mathbf{norm1}$$

- The heat load, along z, as provided by SRUFF at node 1, q_1, is:

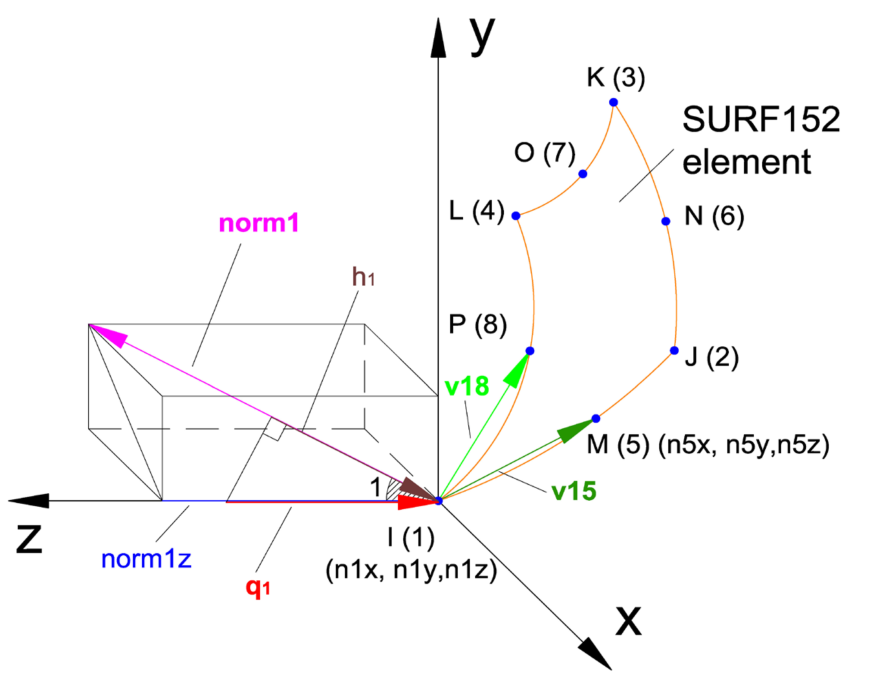
$$q_1 = \exp(a+b*n1x^2+c*n1y^2+d*n1x^4+f*n1y^4+g*n1x^2*n1y^2)$$

- The cosine of the angle between the normal vector, norm1, and z is:

$$cos1 = \frac{|norm1z|}{mod\_norm1}$$

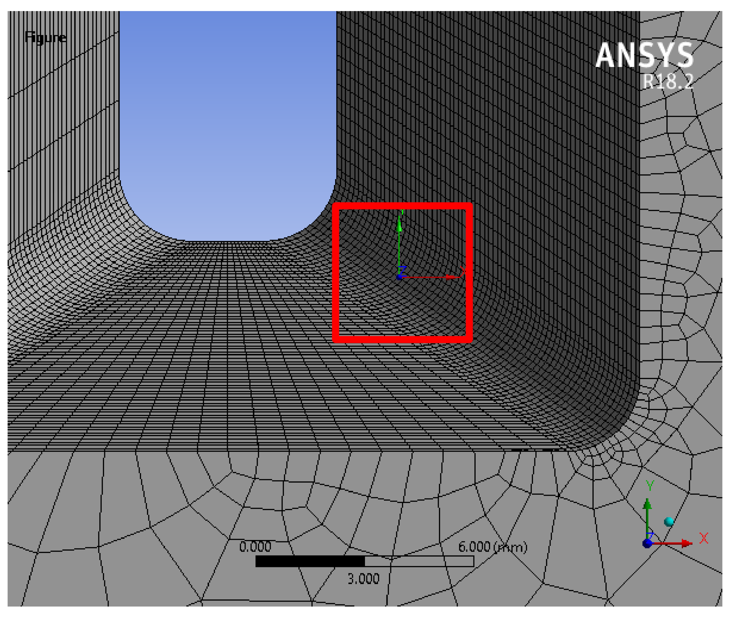
- The length of the normal component of the heat flux at node 1, h1, is:

$$h1 = q_1 * cos1$$



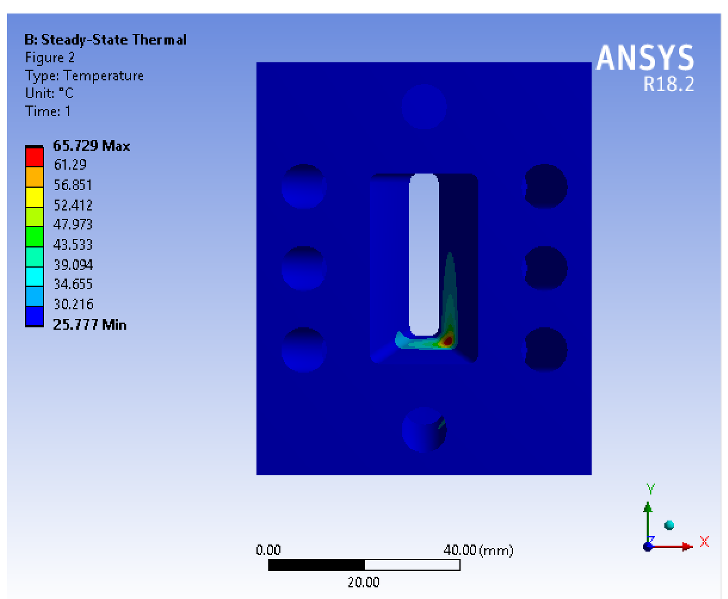
PRE-PROCESSING

- Mesh with quadratic elements (hex dominant); fine mesh the surfaces of interest.
- Define a coordinate system with the origin in the middle of the beam footprint and assign a number, 12, as the APDL name.
- Select the corner and the adjacent sides and create a "Named selection". Call it "E_Surf". Right-click on "E_Surf" and choose "Create Nodal Named Selection". Call it "E_Surf_Nodes".
- Assign material, film coefficient and bulk temperature.
- Insert the Command Snippet.



SOLUTION

- The temperature distribution within the mask body is obtained by running the solution.



COMMAND SNIPPET

```
FINISH
/PREP7
CSYS,12
*GET,ID_MAX_TYPE,ETYP,0,NUM,MAX
ET,ID_MAX_TYPE+1,152
KEYOPT,ID_MAX_TYPE+1,8,1
TYPE,ID_MAX_TYPE+1
CMSEL,S,E_Surf_Nodes
NSEL,R,LOC,X,-1.43,1.43
NSEL,R,LOC,Y,-1.45,1.45
ESURF
ESEL,S,TYPE,,ID_MAX_TYPE+1

*get,ne,elem,0,count
e=0
a=4.3828
………………
*do,i,1,ne
*get,e,elem,e,nxth
*get,n1,elem,e,node,1
*get,n1x,node,n1,loc,x
*get,n1y,node,n1,loc,y
*get,n1z,node,n1,loc,z
………..
v15x=n5x-n1x
v15y=n5y-n1y
v15z=n5z-n1z
v18x=n8x-n1x
v18y=n8y-n1y
v18z=n8z-n1z
norm1x=(v15y*v18z)-(v18y*v15z)
norm1y=(v18x*v15z)-(v15x*v18z)
norm1z=(v15x*v18y)-(v18x*v15y)
mod_norm1=(norm1x**2+norm1y**2
+norm1z**2)**(1/2)
cos1=abs(norm1z)/mod_norm1
a1=a
a2=b*n1x**2
a3=c*n1y**2
a4=d*n1x**4
a5=f*n1y**4
a6=g*n1x**2*n1y**2
aa=a1+a2+a3+a4+a5+a6
h1=1000*cos1*exp(aa)
……………………………
sfe,e,1,hflux,,h1,h2,h3,h4,h5,h6,h7,h8

*enddo
ALLSEL,ALL
FINISH
/SOLU
```

CONCLUSIONS

The purpose of this work was to calculate the temperature distribution on a mask component subject to x-ray beam interception by means of using the commercial FEA software ANSYS Workbench of ANSYS, Inc. A command snippet was developed to allow applying the heat flux load on any surface type of a body. The technique described in this work is applicable to any component subject to x-ray beam interception. The prediction of the temperature distributions is very accurate, therefore it is a reliable tool for the component validation procedure.

REFERENCES

[1] D. Capatina, "A computational and experimental investigation of the heat flux applied by a photon beam", MS thesis, IIT, Chicago, USA, 2008.
[2] Mati Meron, CARS_CAT, "SRUFF: A Comprehensive Package for Synchrotron Radiation Spectral and Optics Calculations", unpublished, 2001.
[3] Jaski, Y *et al.*, "Thermomechanical analysis of high-heat-load components for the canted-undulator front end" in *Proc. MEDSI2002*
[4] ANSYS Inc. (2004). Introduction to ANSYS 9.0 – Part 1: training manual.

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