Curved beryllium window – thermal and vibrational behaviour

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Background

- **Pre-stressed flat Beryllium window (previous design)** --- pre-stress lose when window heats up, causing unpredictable buckle

- **A curved window (current design)** -- will not lose its rigidity under a heat load
What we have done

• Develop a non-stressed Beryllium window
  -- pre-curved window

• Prove that the window works under the given loading conditions
  -- window bows one direction regardless of heat source location

• Conduct FEA studies to validate the design
  -- thermal stress and natural frequency met
Curved Beryllium Window design criteria:

• Low thermal stress under the given temperature gradient

• Predictable window displacement for the given temperature gradient, i.e. ability to deform in one direction regardless of the which side of the window the heat is applied.

• Window thickness – as thin as possible

• Mechanical stiffness – as high as possible

• Cost and manufacturing – to demonstrate cost saving over he pre-stressed flat window.
Double curvature window makes the window more flexible and to allow for freer thermal expansion, hence, less thermal stress.

Non-stressed pre-curved Beryllium window:
Evolution of the pre-curved window

Earlier window geometry:
- Concave radius > convex radius
  - Concave radius: R = 500 mm
  - Convex radius: R = 230.8 mm

Current window geometry
- Concave radius < convex radius
  - Concave radius: R = 300 mm
  - Convex radius: R = 498.11 mm
FEA studies on the pre-curved Beryllium window

**Temperature load** -- maximum temperature at window centre = 100°C and with the following temperature gradient.

**Window thickness** – 3 different thickness have been studied

**2D or 3D** -- Both the 2-D axisymmetric and 3-D brick models of the same geometry were used in the analyses
Window thickness: 0.25 mm

Displacement results:
- Max bow: 2.42 mm

Stress results:
- Max stress: 168 MPa

3-D brick model:
- Max bow: 2.23 mm
- Max stress: 150 MPa

2-D model:
- Max bow: 2.23 mm
Window thickness: 0.38 mm

Displacement results

- Max bow 2.1 mm

Stress results

- 3-D model Max stress 177 MPa
- 2-D model Max stress 170 MPa
Window thickness: 0.5 mm

Displacement results
Max bow 2.02 mm

Stress results
Max stress 184 MPa

Max bow 2.12 mm

2-D model
Max stress 180 MPa
Why the results are slightly different between the 3-D brick and the 2-D axisymmetric models
Displacement results on the 0.25 mm thick window

The 2-D axisymmetric model shows a max. displacement of 2.42 mm

Brick model with 48 elements around the circumference shows a max. displacement of 2.4 mm

Brick model with 24 elements around the circumference shows a max. displacement of 2.23 mm
Stress results on the 0.25 mm thick window

2-D axisymmetric model shows a max. stress of 150 MPa

3-D model with finer mesh

3-D Brick model with 24 elements around its circumference shows a max. stress of 168 MPa

3-D Brick model with 48 elements around its circumference shows a max. stress of 161 MPa
Comments:

3-D model with finer mesh around the circumference tends to converge with the 2-D axisymmetric results
Effect of unequal temperature between the inner and outer surfaces of the Window
**Window thickness: 0.5mm**

With inner & outer surface having the same temperature distribution:
- Max bow: 2.05mm
- Max stress: 184 MPa

With inner surface at 2°C higher than the outer surface:
- Max bow: 1.11mm
- Max stress: 199 MPa

Despite inner surface being at higher temperature than the outer surface, window still bows to the same direction. Peak stress is slightly higher while max. bow is reduced by nearly half.
Comments:

The analysis shows that with inner surface being at higher temperature than the outer surface by as much as 2 Celsius, it is still bowing in the direction as it were at zero temperature gradient through the thickness.

In reality, the through thickness thermal gradient will never be anywhere near 2C because of the window’s relatively thin cross-section.
Frequency analysis on the prototype window geometry

The new geometry – 16cm diameter window
Double curved Be window for 805 MHz cavity: 0.254mm thick and 16cm diameter

Pre-formed the Be foils first at high temperature, brazed copper frames afterwards.
2D axisymmetric FEA model, window thickness 0.254mm (0.01”)  

The 1st frequency mode: **1670Hz** (mesh size 48 x2)  
Refined model 1st frequency mode: **1639 Hz** (mesh size 100 x 2)  

Solution from ALGOR
3D meshed ALGOR model

The 1st mode: **1696** Hz

Good agreement compare with the 1st mode frequency (1670 Hz) from 2D model

Solution from ALGOR
The 2nd and 3rd mode: 2074 Hz

The 4th and 5th mode: 3771 Hz

The 6th and 7th mode: 4211 Hz

The 8th and 9th mode: 4678 Hz

The 10th mode: 5519 Hz

Solution from ALGOR
Double check on the analysis using a different FEA software

The above analysis was repeated using ANSYS. The results are remarkably similar.
The 1st mode: 1667.7 Hz with mesh size 100x2
The 1st mode: 1671.1 Hz with mesh size 60 x 2
The above shows the current mesh density is adequate

Solution from ANSYS
The 1st mode frequency in 3D model is reasonably agree with that of its 2D model’s and also good agreement with ALGOR 3D result (1696 Hz).

Solution from ANSYS
The 2\textsuperscript{nd} and 3\textsuperscript{rd} mode: 2055 Hz

The 4\textsuperscript{th} and 5\textsuperscript{th} mode: 3494 Hz

The 6\textsuperscript{th} mode: 3754 Hz
The 7\textsuperscript{th} mode: 3768 Hz

The 8\textsuperscript{th} mode: 4544 Hz

The 9\textsuperscript{th} mode: 4560 Hz

The 10\textsuperscript{th} mode: 4866 Hz

Solution from ANSYS
Conclusion:

The 2-D & 3D results agree very well. The first frequency is about 1670 Hz.

If the material property of the beryllium deviates from the standard material property by, say, + or – 10%, the frequency will change by about + or – 5%. In this study, we have used a value of 2.89e11N/m^2 for Beryllium’s Elasticity.