Vibration Reduction in X-ray Capillary Optic Fabrication

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![Graph showing measured and fitted slope with designed and measured slopes labeled.]
Capillary Optics

Advantages:
- Work with any X-ray Energy
- Optically & Mechanically Robust
- Efficient

Disadvantages:
- Not Imaging Optics
X-ray Science Application: Art History

Confocal X-ray Fluorescence:
Analyze Buried Layers Non-Destructively

N.C. Wyeth “Family Mural Study” ca. 1945

On Top

N.C. Wyeth “Mildest Mannered Man” ca. 1919

Underneath
Capillary Puller

Tension Stage

Air Stage (Furnace)

Capillary
Capillary Evaluation

Optical Metrology

Beam Line Evaluation

Optical Micrometers

Far Field X-ray Image
Status of Capillary Fabrication Quality

Profile Errors: 0.5-2 µm rms
Slope Errors: 20-80 µrad rms
Structural Bracing

Capillary Puller
View From Above

Air Stage Support
(Holds Furnace & Metrology)

Aluminum Cross Bar

Furnace

Green Bar

To Anchor in Floor

Tension Stage Support
(Holds Capillary on a String)

Capillary in Furnace
Structural Bracing, Continued

Improved Puller Structural Bracing

Aluminum Bar

Steel Unistrut
“Ping Tests in Y-direction”

\[ \tau = 13 \text{ s} \]

In General:
\[ \tau \sim 10 \text{s} \]
“Ping Tests” Continued

Pinged Tension Stage Amplitudes

- Experiment #1 ping tension stage in x
- Experiment # 2 ping tension stage in y

Pinged Air Stage Amplitudes

- Experiment # 3 ping air stage in x
- Experiment # 4 ping air stage in y
"Ping Tests" Continued

Pinged Tension Stage Amplitudes

<table>
<thead>
<tr>
<th>experiment</th>
<th>condition</th>
<th>x-axis amplitude (µm)</th>
<th>y-axis amplitude (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>ping tension</td>
<td>maximum</td>
<td>maximum</td>
</tr>
<tr>
<td>#2</td>
<td>ping tension</td>
<td>maximum</td>
<td>maximum</td>
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Pinged Air Stage Amplitudes

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<tbody>
<tr>
<td>#3</td>
<td>ping air</td>
<td>maximum</td>
<td>maximum</td>
</tr>
<tr>
<td>#4</td>
<td>ping air</td>
<td>maximum</td>
<td>maximum</td>
</tr>
</tbody>
</table>
**Fundamental Frequency Cantilever Prediction**

\[ f_n = \frac{\kappa_n^2}{2\pi} \sqrt{\frac{EI}{\rho AL^4}} \]

- **Air Stage:** \( f_1 = 100 \text{ Hz} \)
- **Tension Stage:** \( f_1 = 45 \text{ Hz} \)
- **Capillary as a String:** \( f_1 = 30 \text{ Hz} \)

\[ I = \frac{bd^3}{12} \]

\[ \kappa_1 = 1.875 \]
Predictions v. Observations

• Predicted Frequencies Too High

• Maximum Measurable Frequency 5 Hz

• Source of Vibrations Not Air or Tension Stage Supports
Present Capillary Status

Radius Profile

- Designed radius
- Fitted focal length = 29 mm
- Measured radius
- Tip fitted div. = 1.8 μrad
- Fitted radius
- Difference between the Fitted and Measured radius (10x)
- RMS Profile error: 0.12156 microns

Measured and Fitted Slope

- Fitted slope in x
- Measured slope (20 point running ave) - RMS error: 13 urad
- Measured slope (no ave) - RMS error: 15 urad

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Suggestions for Further Improvement

- Further stiffen the mechanical stages against vibrations
- Does ‘string mounting’ of capillary amplify the vibrations?
- Need improved metrology—Need more sensitive on-board optical equip. Off-line viewing of Capillary Interior profile?

New Structural Bracing
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