Characterization of the error budget of the Alba-NOM

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ALBA light source
We aim to characterize the uncertainty of slope measurements obtained by the Alba-NOM, contributed by stochastic effects and systematic errors:

1. The bench
   a. Motion metrology
   b. Raytracing of the guidance induced error
   c. Vibrations, noise and stability

2. The optics
   a. Calibration using redundant-independent datasets.
   b. Optimization of the iris aperture.

3. One application
   a. Surface correction using few point forces
   b. Exsitu vs Insitu
The use of a differential interferometer allows an accurate characterization of the motion performance of the bench.

- **Resolution (linear)**: 1 nm
- **Resolution (angular)**: 41 nrad
- **Maximum sampling rate**: 5 kHz
- **Noise level**: ~0.1 nm RMS
- **Accuracy (linear)**: ±0.7 p.p.m
- **Linearity (angular)**: ±0.5 μrad

![Time signal](Image1.png)

![Spectrum](Image2.png)
The use of a differential interferometer allows an accurate characterization of the motion performance of the bench.

<table>
<thead>
<tr>
<th>Position</th>
<th>Backlash</th>
<th>Accuracy</th>
<th>Repeatability</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 nm</td>
<td>3.5 µm</td>
<td>77 nm</td>
<td>20 nm</td>
</tr>
</tbody>
</table>

**Resolution, a 40 nm step**

**Positioning error**
## Guidance measurements

<table>
<thead>
<tr>
<th></th>
<th>Backlash</th>
<th>Accuracy</th>
<th>Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pitch</strong></td>
<td>2 nrad</td>
<td>7.1 urad</td>
<td>200 nrad</td>
</tr>
<tr>
<td><strong>yaw</strong></td>
<td>390 nrad</td>
<td>10.1 urad</td>
<td>94 nrad</td>
</tr>
<tr>
<td><strong>roll</strong></td>
<td>&lt;115 nrad</td>
<td>6.1 urad</td>
<td>&lt;200 nrad</td>
</tr>
<tr>
<td><strong>flatness</strong></td>
<td>14 nm</td>
<td>1.1 um</td>
<td>42 nm</td>
</tr>
<tr>
<td><strong>straightness</strong></td>
<td>2 nm</td>
<td>2.1 um</td>
<td>47 nm</td>
</tr>
</tbody>
</table>

**Graphs**

- **Pitch**
- **Yaw**
- **Flatness**
- **Straightness**
Double pass raytracing of the scanning pentaprism is used to determine the influence of guidance error on the measurement.
**Guidance accuracy**

**R = 100 m**

**Contribution of the guidance error to the LTP error**
**Guidance accuracy**

### Different spheres

- \( R=50 \text{ m} \): 33 nrad RMS
- \( R=100 \text{ m} \): 17 nrad RMS
- \( R=200 \text{ m} \): 6 nrad RMS
- \( R=500 \text{ m} \): 3 nrad RMS

### Pentaprism error – \( R=100 \text{ m} \)

- \( \varepsilon_A = -0.50 \text{ mrad} \): 57 nrad
- \( \varepsilon_A = -0.25 \text{ mrad} \): 34 nrad
- \( \varepsilon_A = +0.00 \text{ mrad} \): 17 nrad
- \( \varepsilon_A = +0.25 \text{ mrad} \): 23 nrad
- \( \varepsilon_A = +0.50 \text{ mrad} \): 45 nrad

### Different spheres – Position LUT

- \( R=50 \text{ m} \): 11 nrad RMS
- \( R=100 \text{ m} \): 6 nrad RMS
- \( R=200 \text{ m} \): 3 nrad RMS
- \( R=500 \text{ m} \): 1 nrad RMS

### Pentaprism roll – \( R=100 \text{ m} \)

- \( \text{roll} = -2.00 \text{ mrad} \): 14 nrad
- \( \text{roll} = -1.00 \text{ mrad} \): 9 nrad
- \( \text{roll} = +0.00 \text{ mrad} \): 17 nrad
- \( \text{roll} = +1.00 \text{ mrad} \): 32 nrad
- \( \text{roll} = +2.00 \text{ mrad} \): 66 nrad

**Source:** www.cells.es
Guidance accuracy

Different spheres

Position LUT solves main errors

Pentaprism roll – R=100 m

Accurate + aligned pentaprism is essential (+ unexpensive)
Although the amplitude of the vibration in the ground is 50 nm RMS, the measurement on top of the NOM is 13 nrad RMS.
Redundant-independent datasets

The use of redundant-independent measurements of a mirror allows to estimate the slope error and the linearity error of the instrument.

The resolution of the surface is limited

- Validity of the error model \( \rightarrow \) short mirrors vs long mirrors
- Noise of each measurement
- Number of measurements

Simulation: accuracy dependence on noise

Simulation: accuracy dependence on number of datasets

A 100 mm, R=75 m sphere has been used to cover 12 mrad range of the NOM.

Each reconstruction is based on 54 scans

Residual aberration + periodic subpixel interpolation error found for two different roll positions of the pentaprism.
For small apertures uncertainty is limited by noise and repeatability
For larger apertures, the error increases, mainly, due to the loss of lateral resolution
Slope error optimization

For whatever correction technique, accuracy of metrology is a limit to the achievable slope error.

Simulation of the achievable slope error with 2 actuators, as a function of the measurement error.

Mirror figure measured by the pencil beam method matches the profile optimized to 55 nrad at the Alba-NOM 2 years ago.
Conclusions

Positioning error correction (LUT) and accurate pentaprisms allow reducing the bench induced error to the few nanoradian.

The usage of redundant-independent datasets allow an accurate modeling of the optics induced error.

Using them, also allows reducing the iris aperture, to increase spatial resolution preserving accuracy.

The measurements provided by the NOM are accurate enough to optimize the mirror figure to nanometer accuracy.
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Thank you for your attention