Nanometer correction of bendable mirrors by spring actuators

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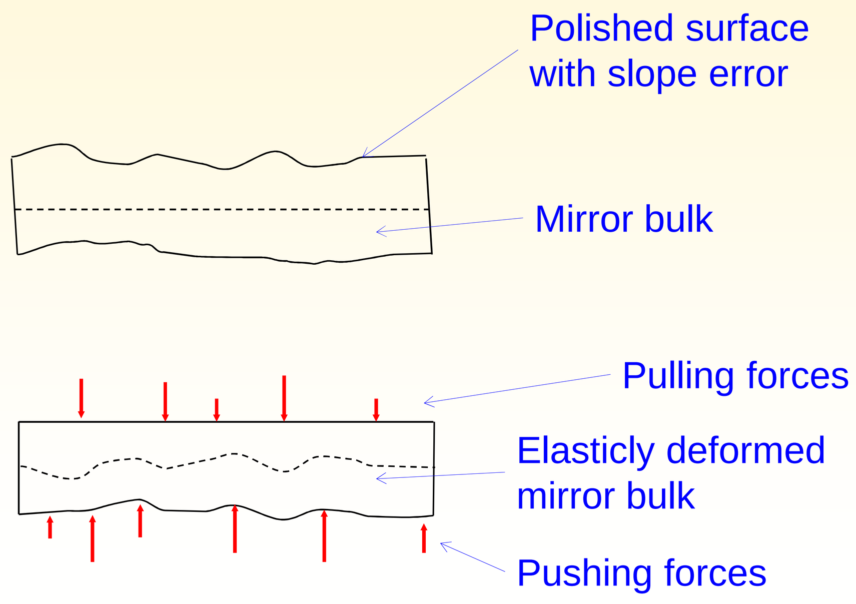
Abstract

We present a project to develop a system capable to obtain accurate mirror figures by compensating the polishing slope error with the elastic deformation introduced by means of point spring actuators. The use of point spring actuators has been normally used to correct the figure error introduced by the gravity sag of the mirror bulk, with good results. In these cases, the springs introduce a controlled deformation described by the elastic beam theory, which compensates, partly, the gravity sag. The same principle can be extended to correct the residual slope errors due to polishing. For this, the mirror holder needs to be able to push or pull the mirror at selectable positions, and the force exerted by the actuators needs to be adjustable with good resolution. The limitation of the technique is given by the spatial frequency of the slope errors one can correct, the accuracy of the measurements of the metrology, and the resolution and stability of the forces exerted by each actuator. In order to minimize the effect of the latter, a method based on the usage of a minimum number of actuators is proposed. The proposal provides an unexpensive technology that allows reaching figure errors in the nanometer range avaliable also for long mirrors. The results obtained with a first experience of the technique are given, and the scalability of the method is analyzed in this work.

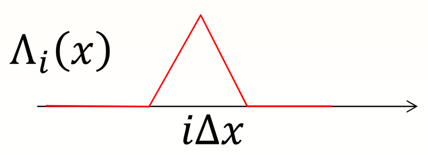
Concept

A number of point forces is used to obtain the elastic deformation of the mirror substrate that compensates the figure error, as measured by the NOM.



$$-E\frac{bh^3}{12}\frac{d^2z(x)}{dx^2}=\sum_{i=1}^{N}m_i\Lambda_i(x)$$

$$\begin{pmatrix} m_1\\ \vdots \\ m_i \\ \vdots \end{pmatrix} = \Delta x \begin{pmatrix} 1 & 0 & 0 & \cdots \\ 2 & 1 & 0 & \\ 3 & 2 & 1 & \\ \vdots & & & \ddots \end{pmatrix} \begin{pmatrix} F_1\\ \vdots \\ F_j \\ \vdots \end{pmatrix}$$



The elastic beam theory states that for *N* actuators, a (*N*-1)-segment cubic piecewise polynomial can be corrected.

In order to achieve the required force resolution and system stability, very weak springs are used.

A miminum number of actuators is introduced so as to avoid the error induced by their unstability. The position of each one of the actuators is optimized using a simplex algorithm.

Project

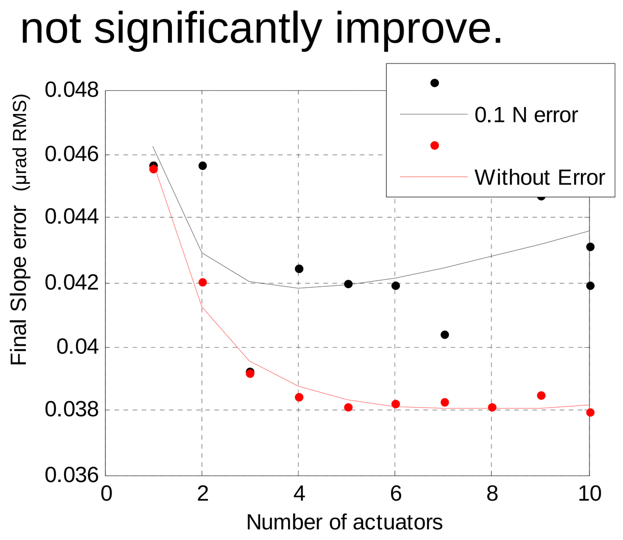
ALBA is running a development project to build a prototype.

- Length 1 m,
- Moderate curvature bender (5 km)
- Surface error below the 1 nm

- Conceptual design finished in May'12
- The detailed design of a prototype to be ready in Oct'12.
- A prototype, using a low quality mirror to be ready by spring'13

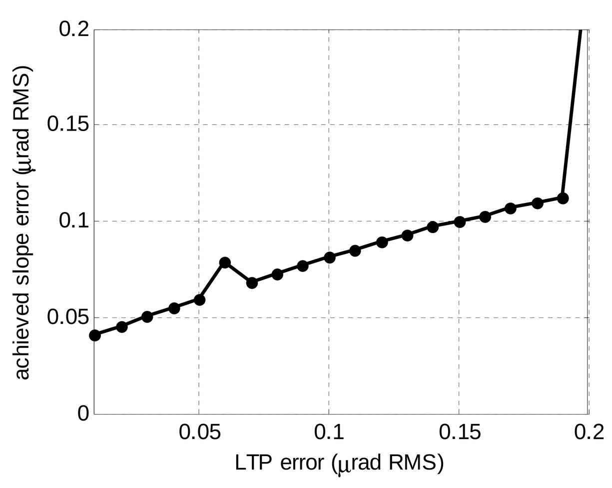
Design Challenges

The sensitivity to mechanical drifts of the actuator forces increases when a higher number of actuators is used, while the slope error does not significantly improve.



Achieved slope as a function of the applied actuators, with error on the applied forces.

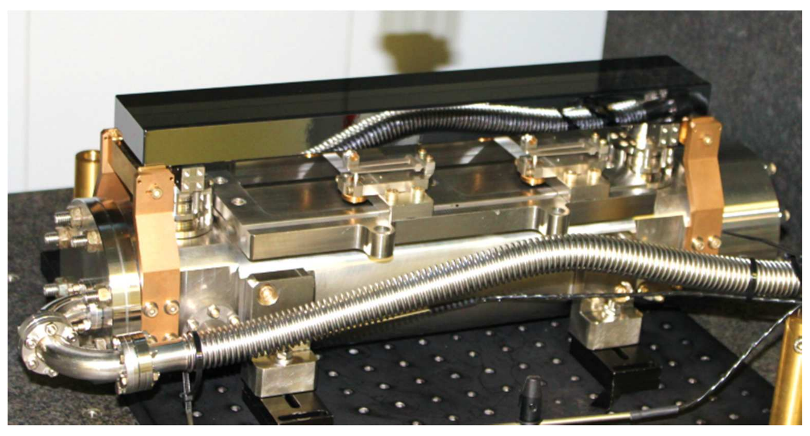
The measurement error of the LTP is also a limiting factor of the slope error one can achieve.



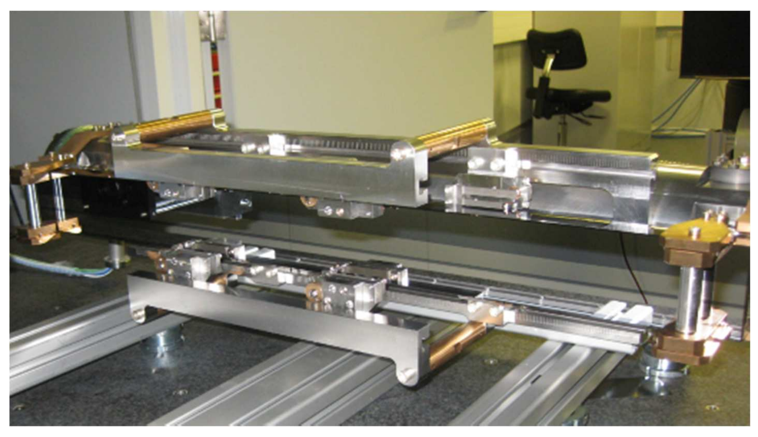
Achieved slope error as a function of the LTP measurement error, for 3 actuators

Preliminary results

The proposed technique has been successfully applied to the two KB benders installed at the XALOC beamline at ALBA. The convergence was limited by the poor resolution of the spring correctors



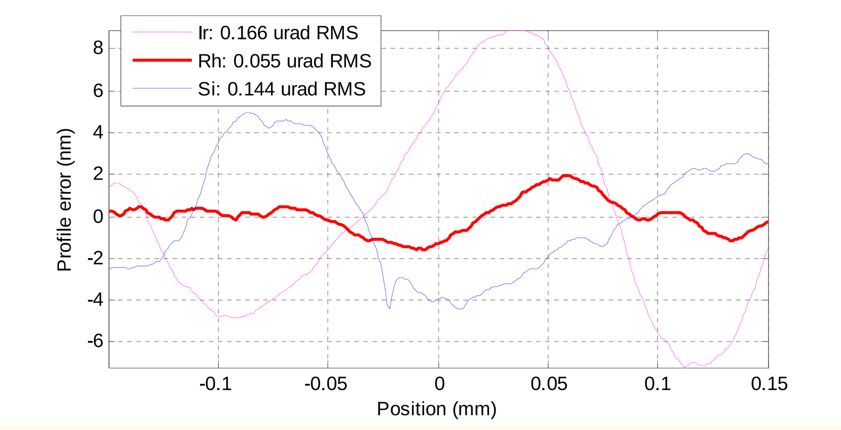
VFM mirror 300 mm
Initial slope error: 0.24 µrad
Corrected slope error: 0.06 µrad



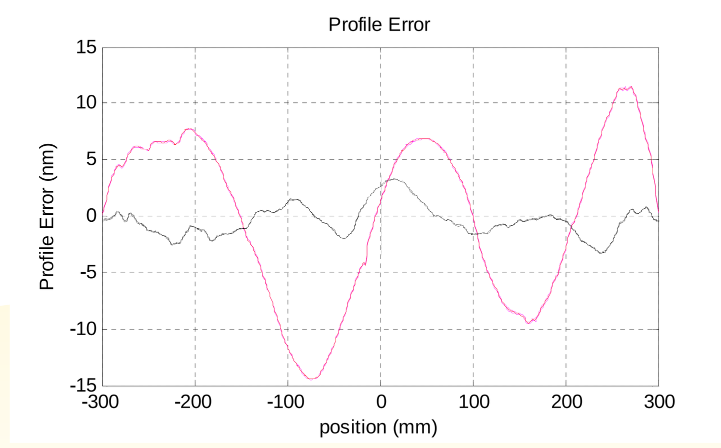
HFM mirror 600 mm
Initial slope error: 0.21 µrad
Corrected slope error: 0.08 µrad

Optimization flat

As a first step, the surface error is corrected ignoring the contribution of the best fit cubic polynomial



Uses 2 actuators
Initial slope error: 0.24 µrad
Corrected slope error: 0.055 µrad

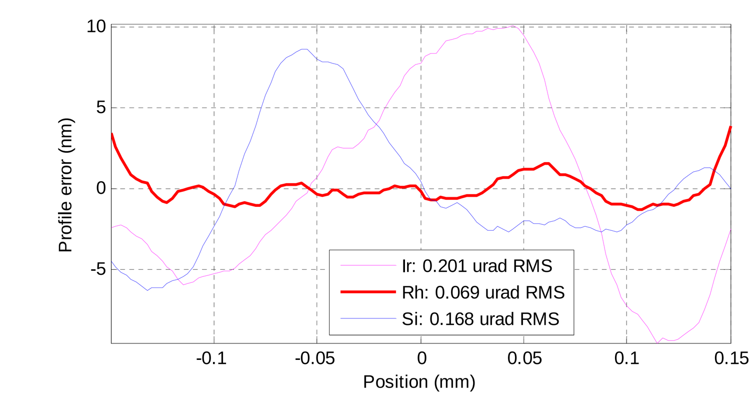


uses 4 correctors
Initial slope error: 0.21 µrad
Corrected slope error: 0.08 µrad

Ellipse calibration

Once the flat error is done, the mirror is bent to the nominal ellipse:

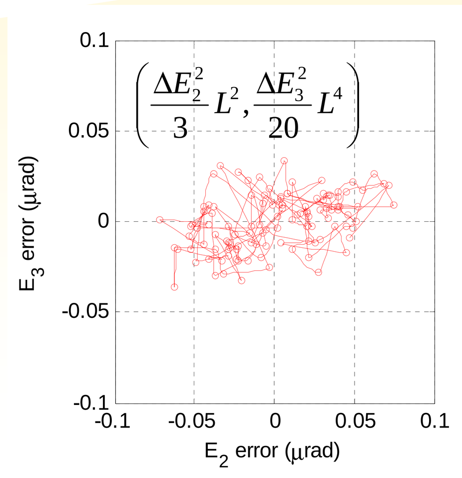
1) An algorithm to do this automatically has been developed
2) The error residual from the best fit ellipse matches the residual error from flat



With the exception of the ends, which show a local effect of the bender clamps, the profile is equal to the figure measured flat.

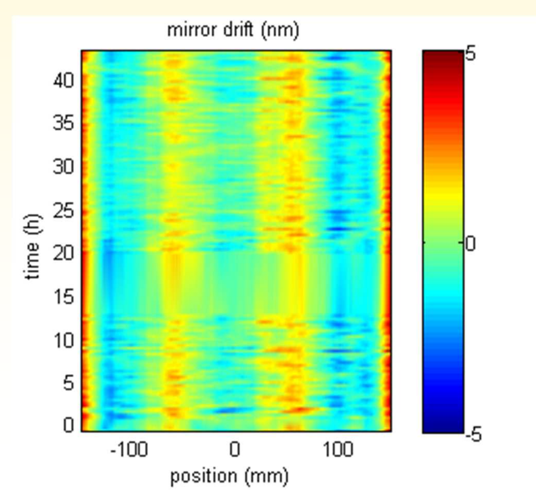
Stability

Once the system is set to the nominal ellipse, its shape and error are monitored during 48 hours, with no significant change in the slope error.



Stability of the bender in 48h
← Variation of the ellipse parameters, in slope error units

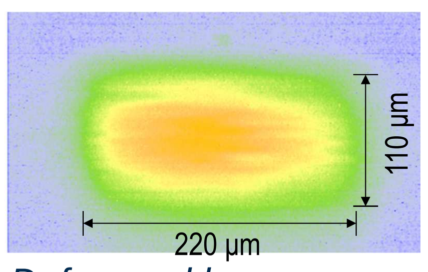
Variation of the residual height profile,without any drift above the residual slope error. →



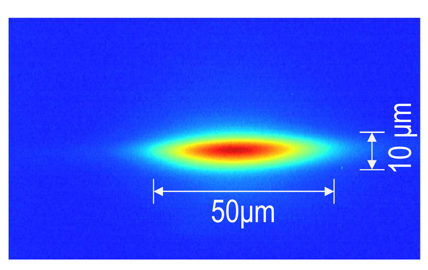
Beamline results

The mirror installed at the beamline achieves the nominal spot size as well as a very homogeneous defocused beam.

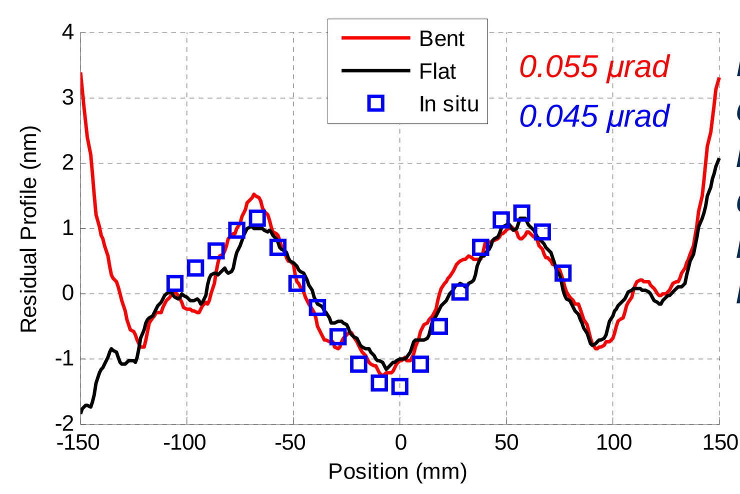
In situ measurements of the surface error, by the pencil beam technique, provide evidence that the slope error correction is held after 2 years.



Defocused beam



Focused beam



Residual slope error of the XALOC VFM, measured in Flat condition, at the nominal ellipse, and in-situ

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