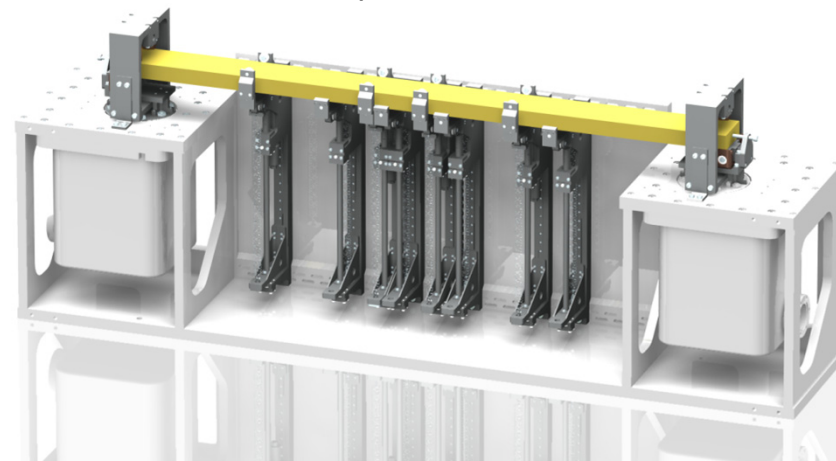


The Nanobender: a New X-Ray Mirror Bender with Nanometer Figure Correction

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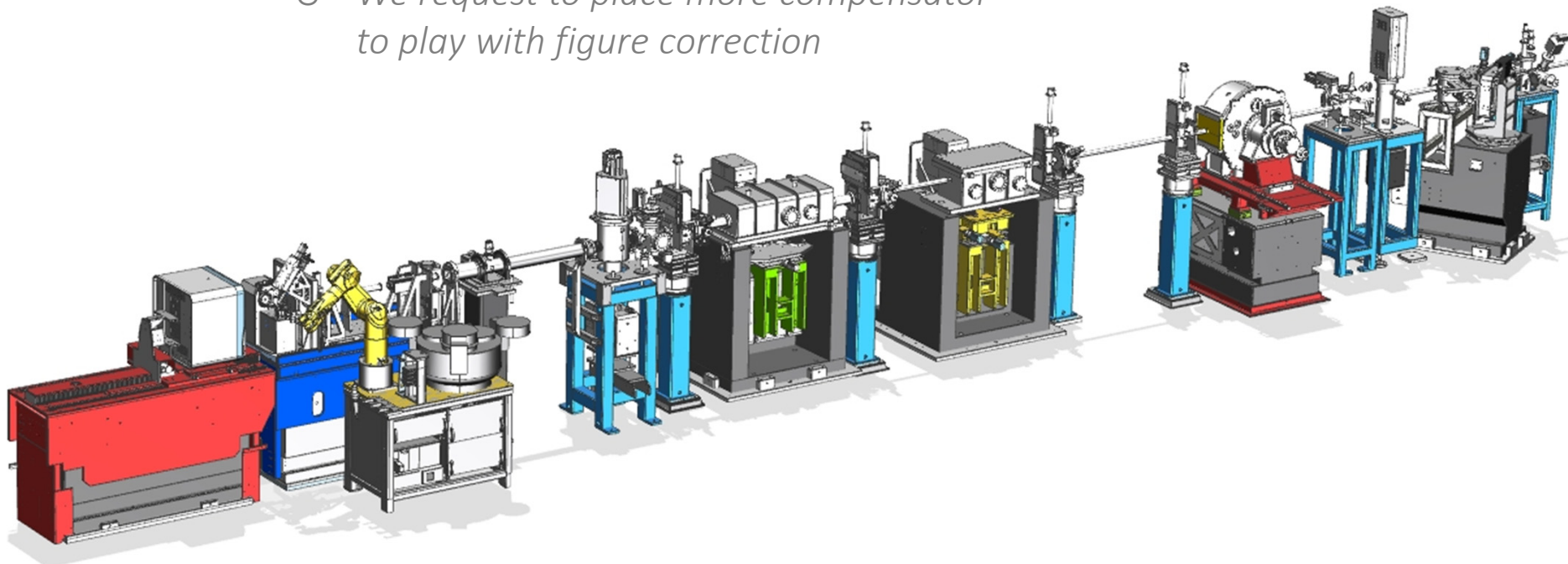


Presentation Summary

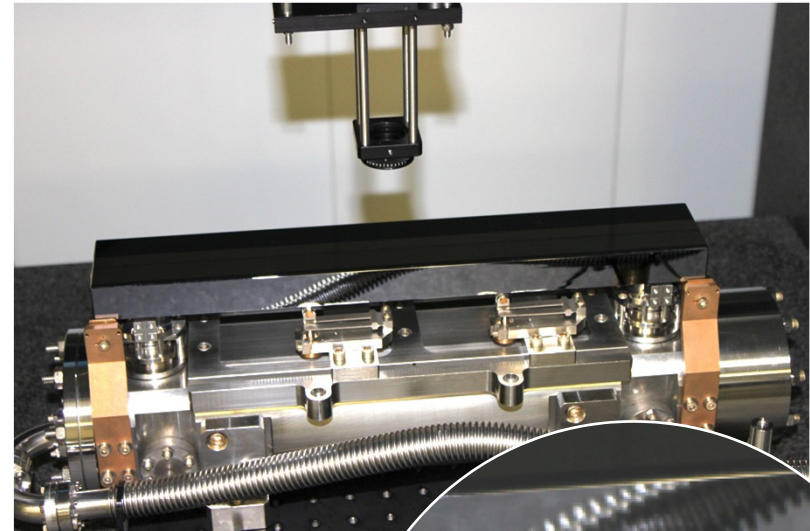
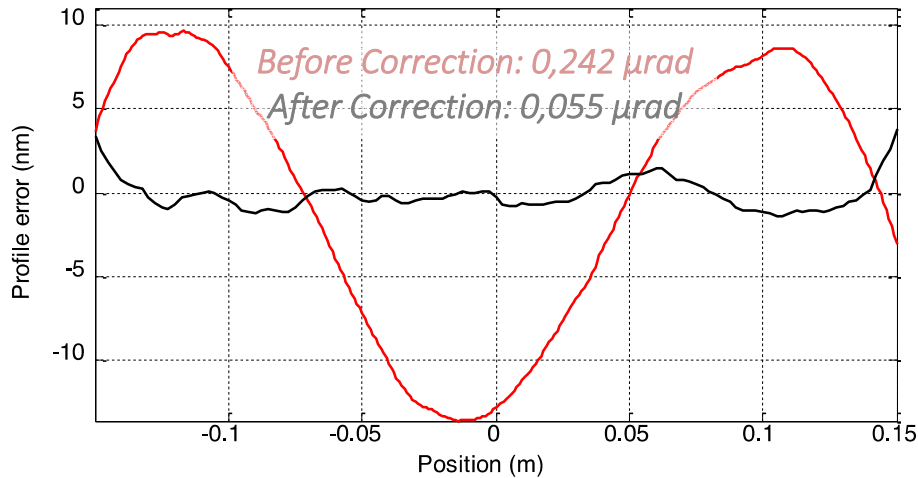
- *Precedents*
- *New concepts*
- *Bender design*
- *Correctors design*
- *Construction*
- *Measurements & Results*
- *Next Steps*
 - *Active Optics*
- *Conclusions*

ALBA BL13 Beam Line

- Protein Crystallography Beam Line
- Vertical Focusing Mirror: Outsourced
 - Include a Gravity compensators
 - We request to place more compensator to play with figure correction



BL13 VFM Optimization



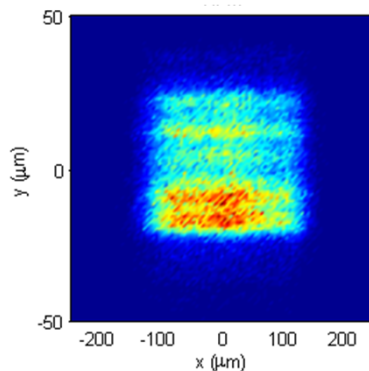
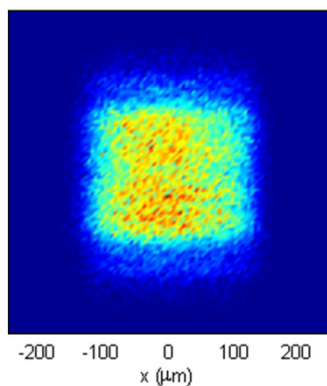
Mirror by Insync
Bender by Irelec

- We corrected the slope error by means the gravity compensators
- Optimization of the compensators position
- Manual compensators
- This compensators are not thought for this function: not friendly adjustment

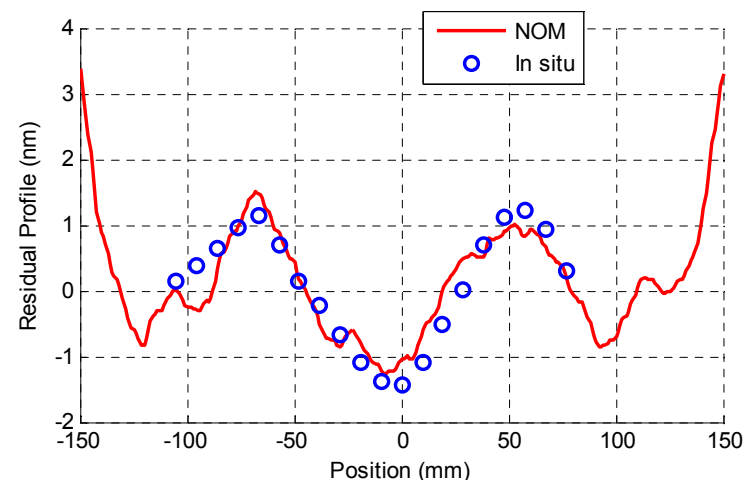
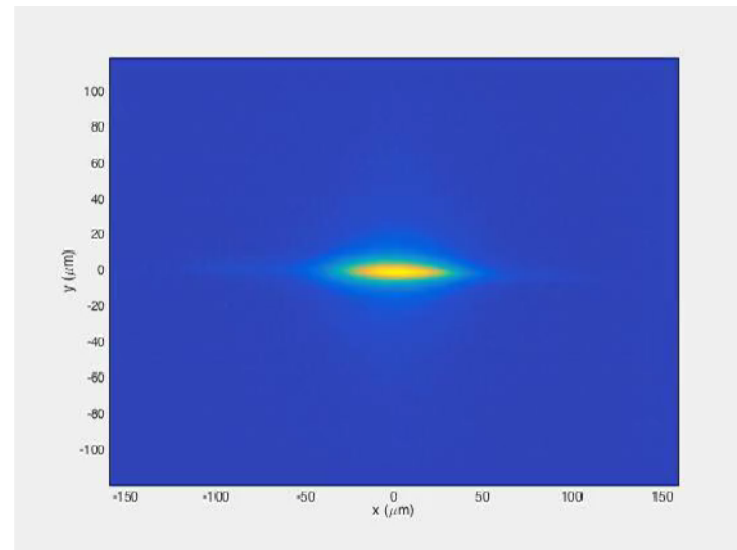
*This 300 mm long mirror was optimized from 0,242 μ rad to 0,055 μ rad
By means two of the gravity compensators both pushing from below*

BL13 VFM In-Situ measurement

The simulation of the beam by means ray-tracing with the measured corrected mirror figure



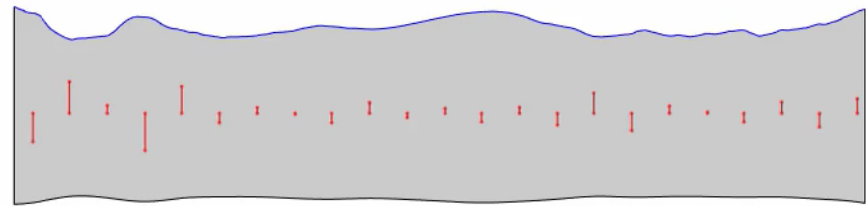
In-Situ measurement after 2 years agrees with the laboratory optimization and measurement



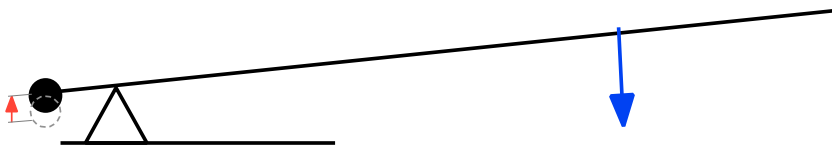
Geometrical vs Force constrains

*Optical surface
with slope error*

Applied Forces

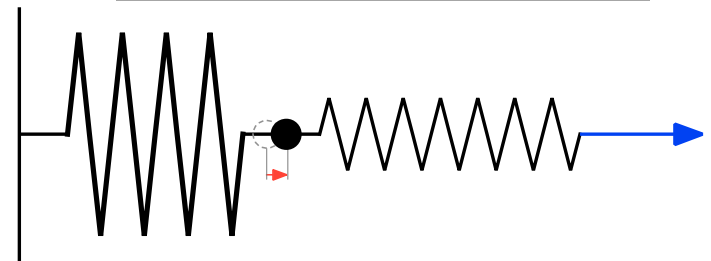


The hard way



*By means Rigid mechanics which
introduce the required deformation*

The soft way

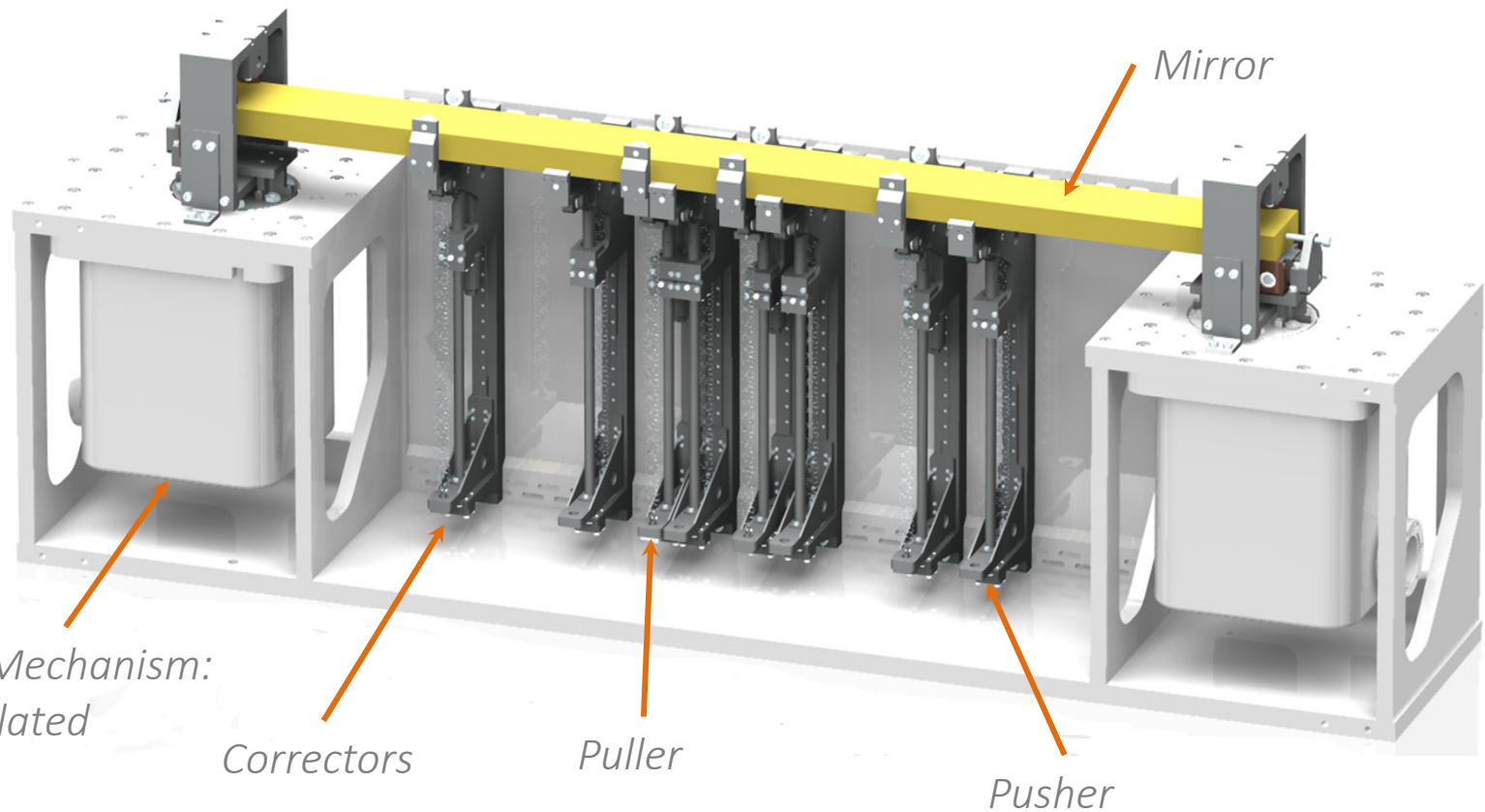


vs

*...By means of stable-force
actuators"*

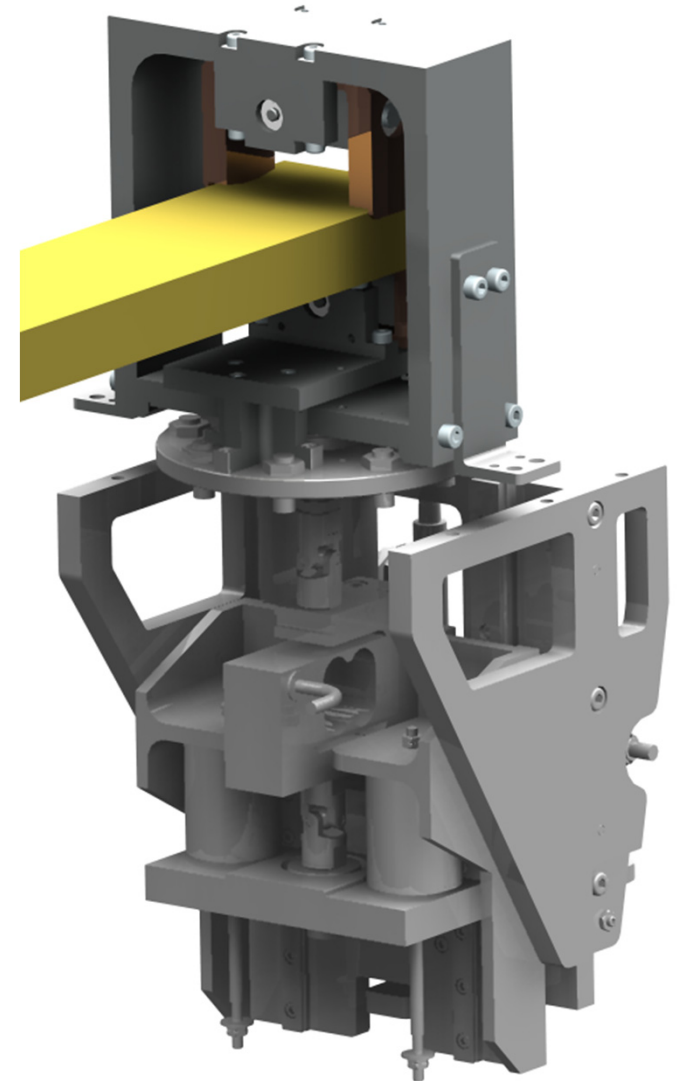
Bender design

Lay-out



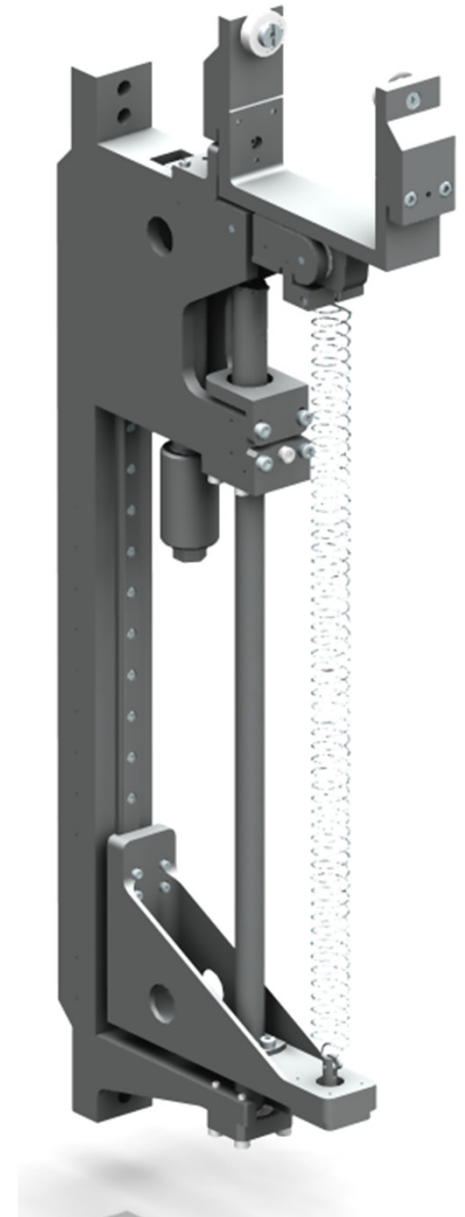
Bender Mechanism

- *Based on compression springs*
- *Convectional motion system for the compression Range*
- *Force gauge measurement*
- *Off-axis relieving Force transmission*
- *Punctual contacts*
- *Flexion at 25 mm from the support*
- *Radius of curvature: 500 m*
- *Forces up to 500 N*
- *Force Resolution: 0,001 N*
- *Focus independent of figure correction*



The correctors

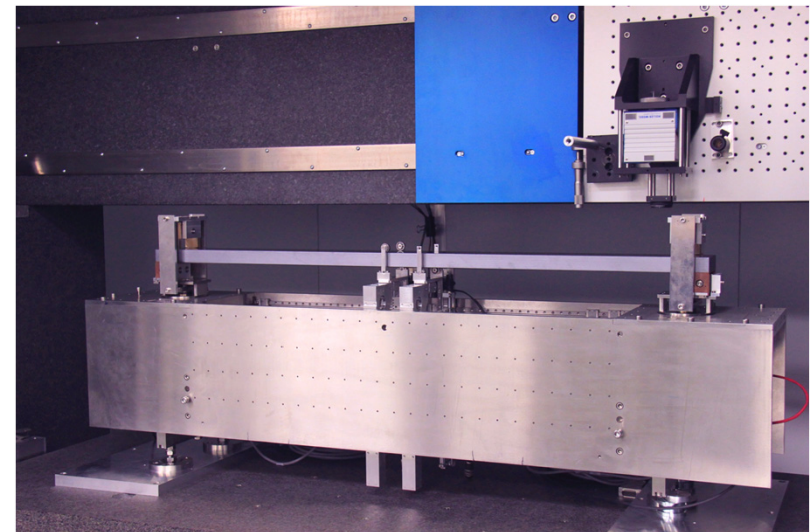
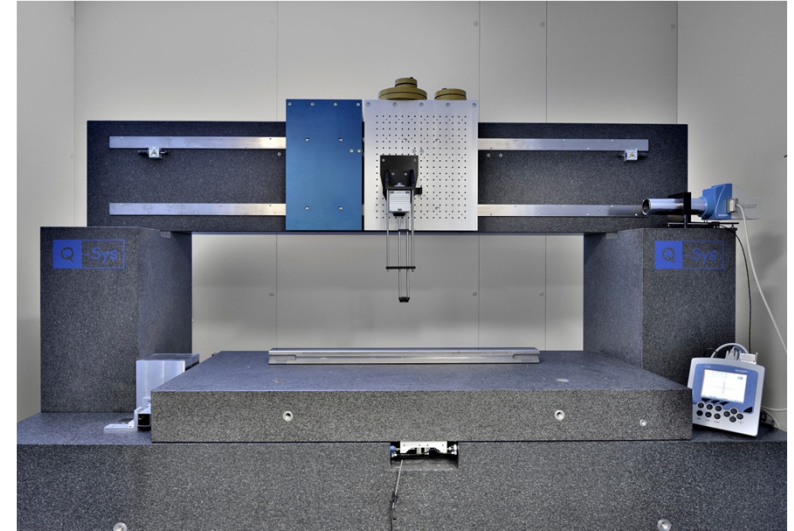
- 22 mm width
- High resolution force correctors
- Ultra low k springs
- Forces up to 40 N, ± 20 N.
- Resolution up to 0,001 N
- High stability:
 - Independent to the set curvature, no crosstalk
- No parasitic torsions
- UHV compatible (adaptive optics)



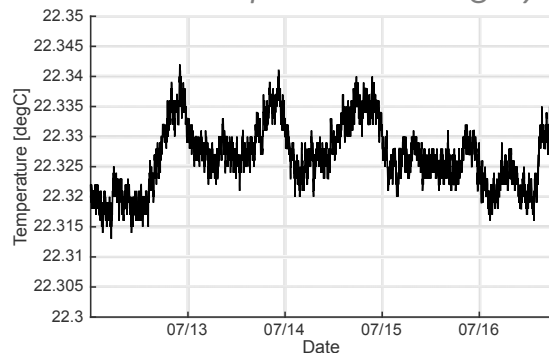


ALBA NOM

- *This is a 1,5 m long highly accurate scanning deflectometer by air bearings*
- *Ironless linear motor*
- *Optical set-up*
 - *Autocolimator*
 - *Pentaprism*



The laboratory temperature is stabilized by means of a PID controlled post-heating system

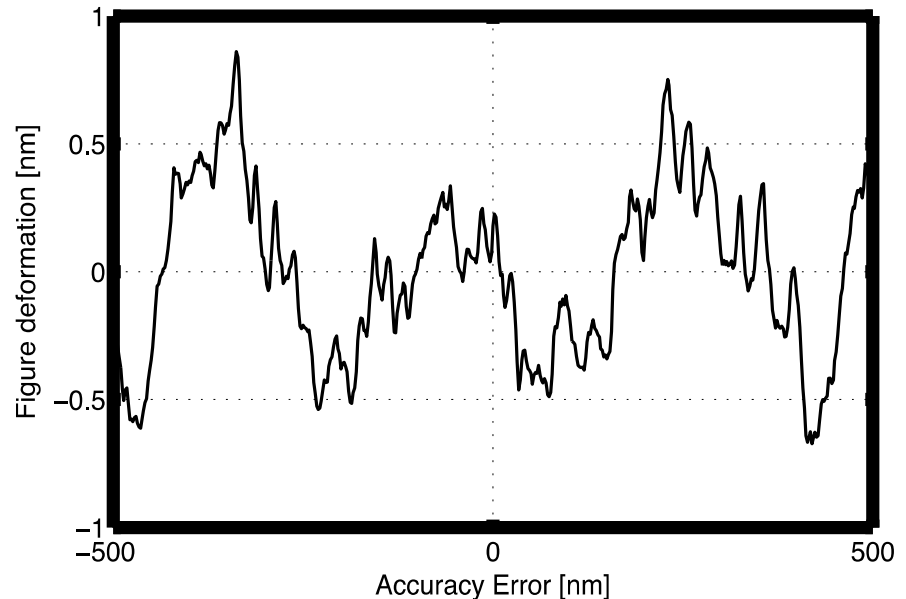
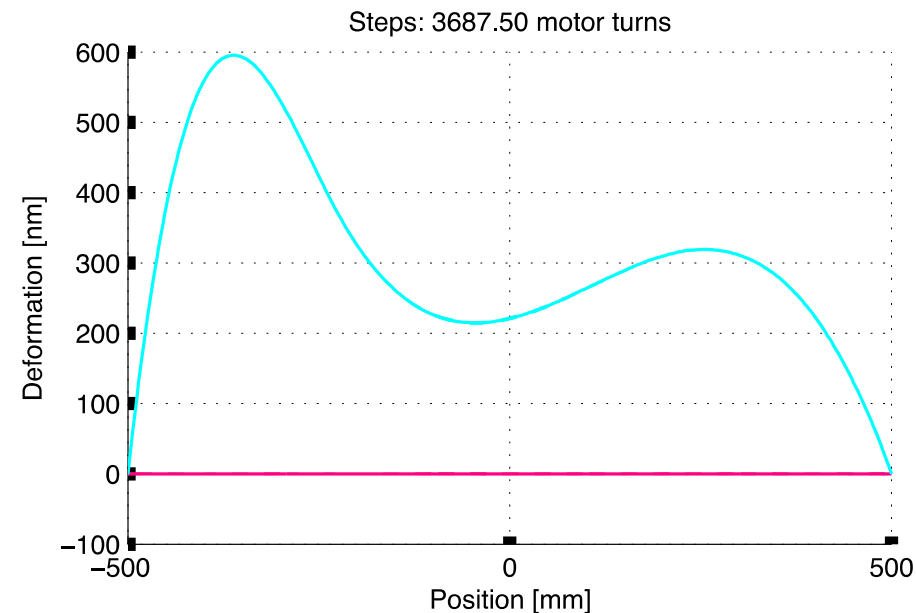


Mathematical deformation Model

Euler – Bernoulli law

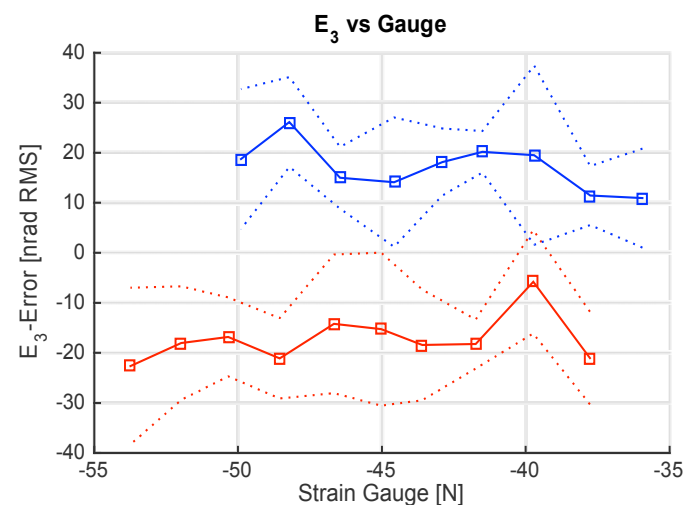
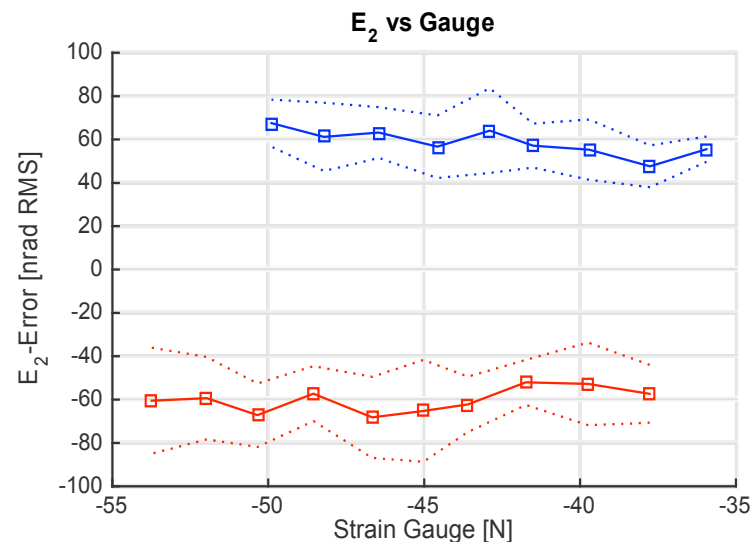
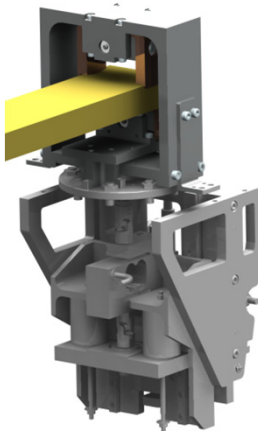
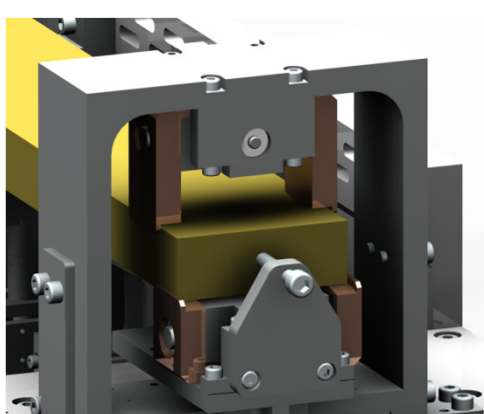
$$EI \frac{d^4}{dx^4} z(x) = \sum_{n=1}^N F_n \delta(x - x_n)$$

- *LINEAR model, allows superposition*
- *Curvature of deformation is a piecewise linear function*
- *Surface deformation is a piecewise cubic polynomial*
For an induced deformation of >600 nm after removing curvature, the model is accurate below 1 nm



Bending performance

Performance	Figure
<i>Bending range</i>	0-500 N
<i>Bending resolution</i>	<0.001 N
<i>Strain gauge sensitivity</i>	16 nrad rms
<i>Actuator linearity</i>	35 nrad
<i>Bending repeatability</i>	15 nrad rms
<i>Stability</i>	<15nrad/5days

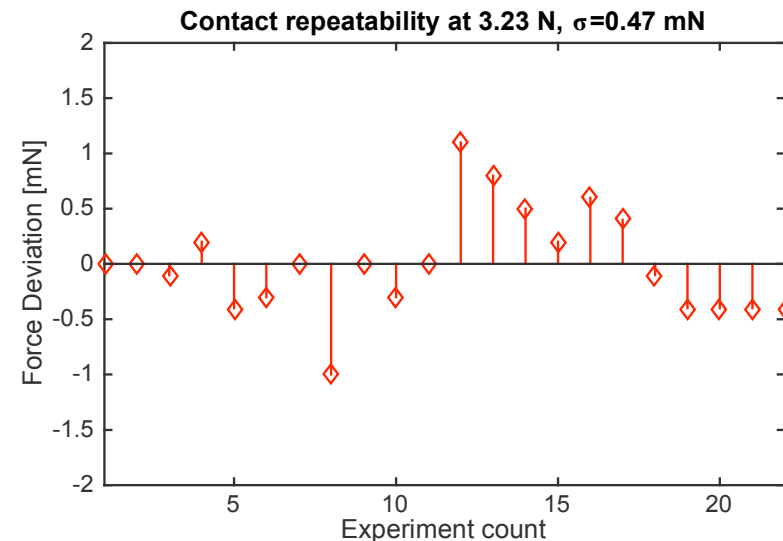
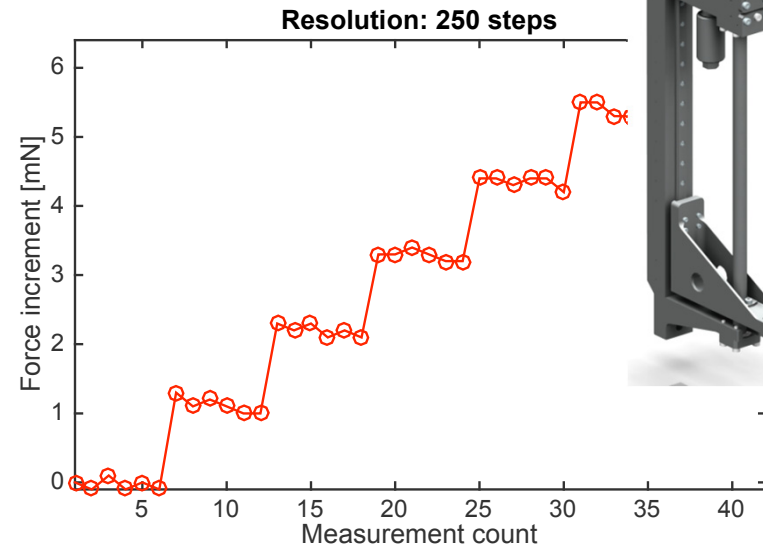


Measurements & results

Correctors performance

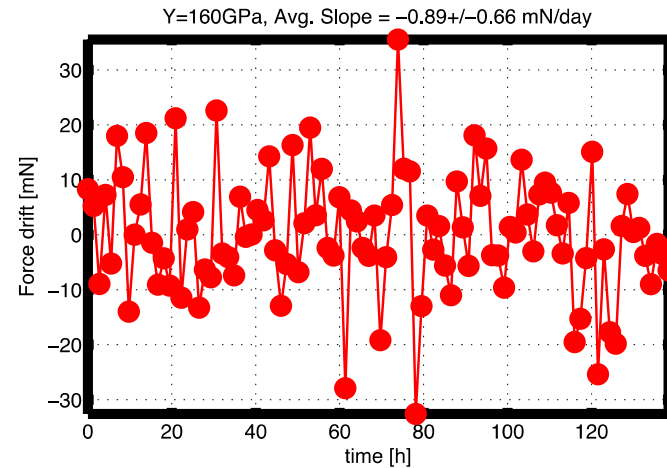
Resolution of 0.001N allows sub nanometer correction, as well as stability

20 N is the force estimated to correct 0.5 μ rad rms mirrors for errors with period down to 22 mm

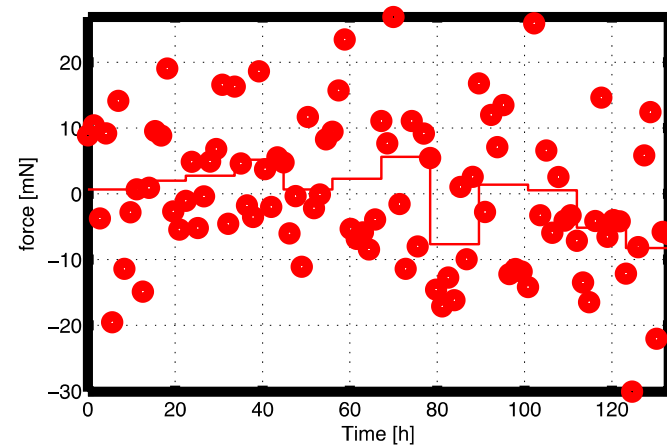


Correctors performance

Stability for 130h



Repeatability on recovering a position between motions to random points



Mirror Optimization

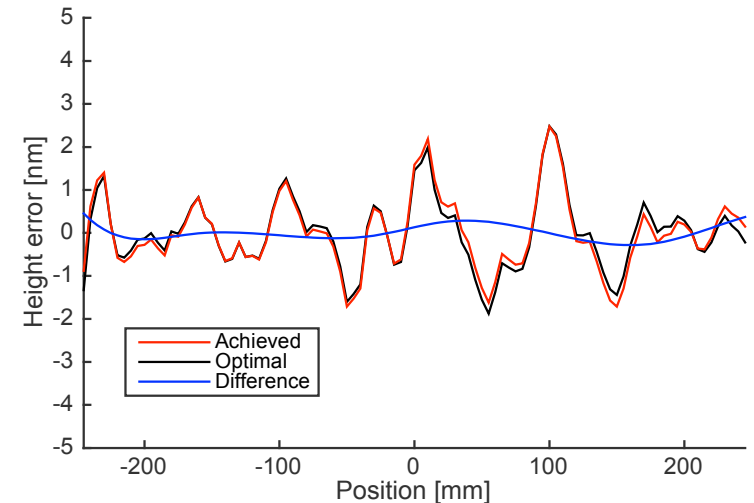
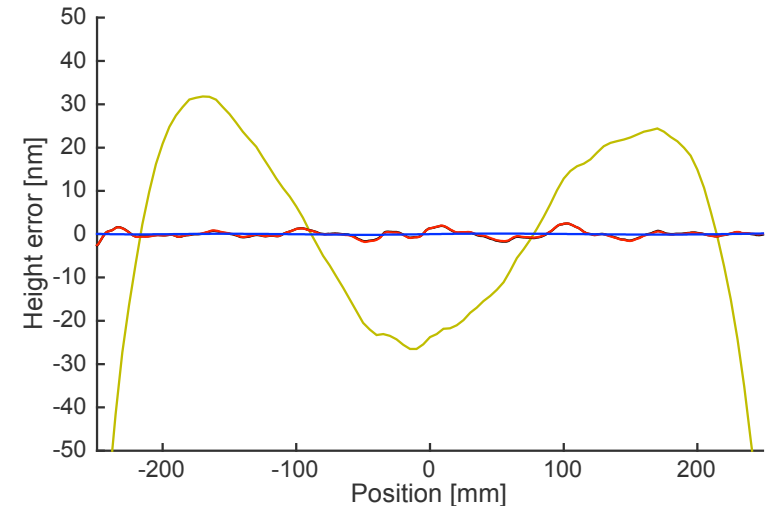
Initial slope error: $0,87 \mu\text{rad RMS}$
 Corrected slope error: $0,115 \mu\text{rad RMS}$

Initial surface error: $23,2 \text{ nm RMS}$
 Corrected surface error: $0,858 \text{ nm RMS}$

The mathematical model:

- Optimizes the correctors position
- Optimizes the corrector force (and its sense)

The model predicts the deformation of the mirror with accuracy better than 0.08 nm RMS

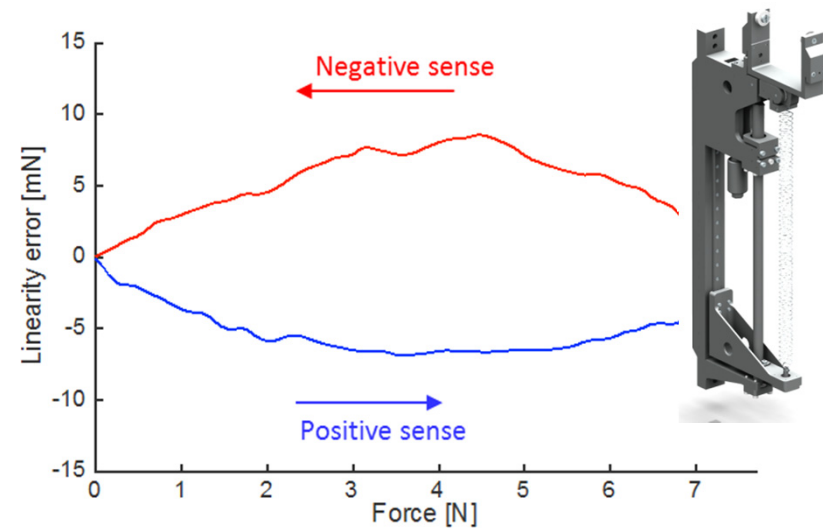


Next steps

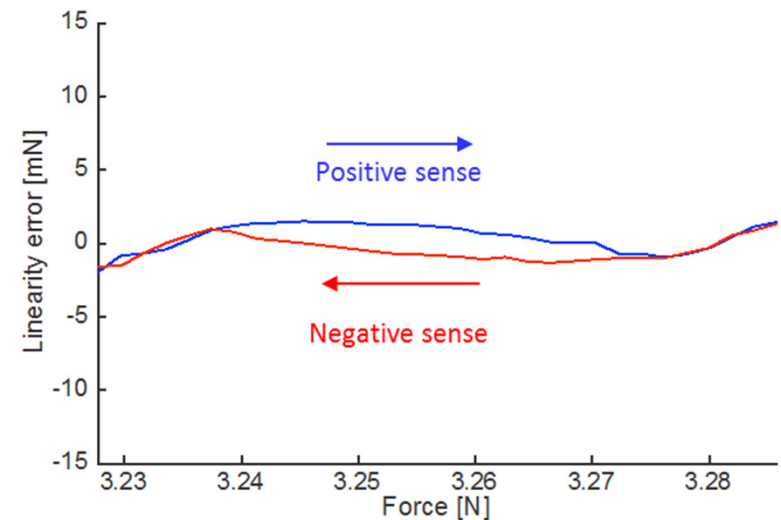
Corrector Improvements

- *Corrector Repeatability: Done*
- *Remove the bender mechanics encapsulation*
- *Compact the bender mechanism*
- *Compact the correctors*

Repeatability Long Range

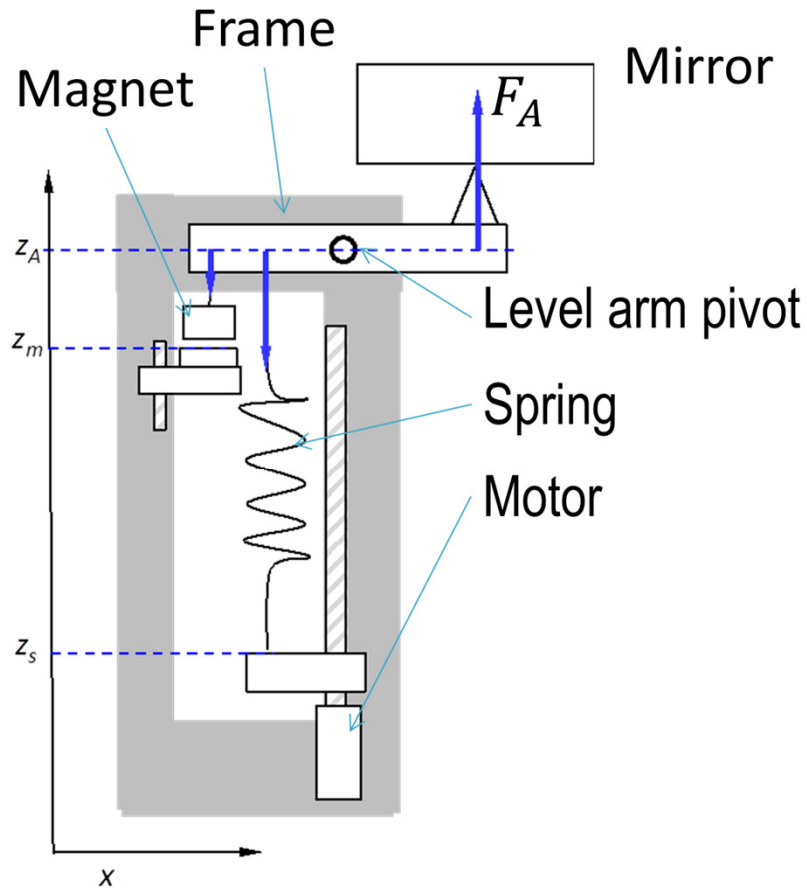


Repeatability Short Range

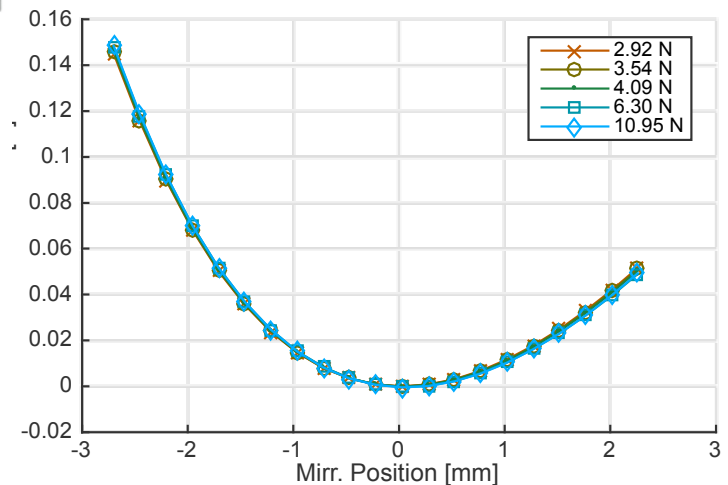


Next steps

Corrector Improvements



- $-k$ magnet system for spring k compensation
- Insensibility to magnet position in a ± 1 mm



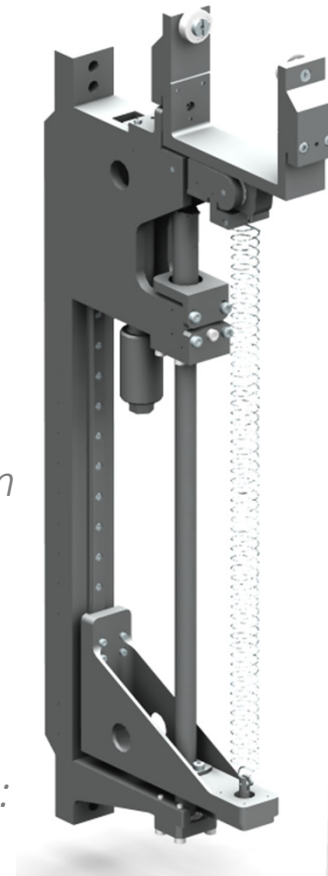
Corrector Improvements

To be implemented soon

- Spring length reduction by means the force compensation system:
 - Test prototype done and measured.
 - -k spring with magnet.
- Removal of the bearing friction on the spring articulation:
 - Test prototype done
 - Zero-torque frictionless articulation
 - By means a flexure and magnet system

See the poster :

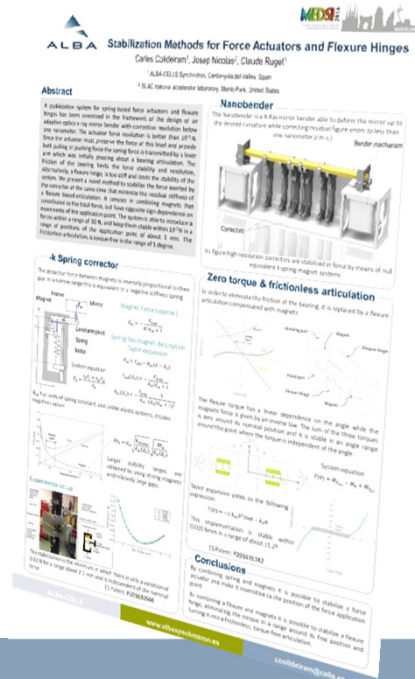
ID: 2029 - MOPE01 Stabilization Methods for Force Actuators and Flexures



Three patents

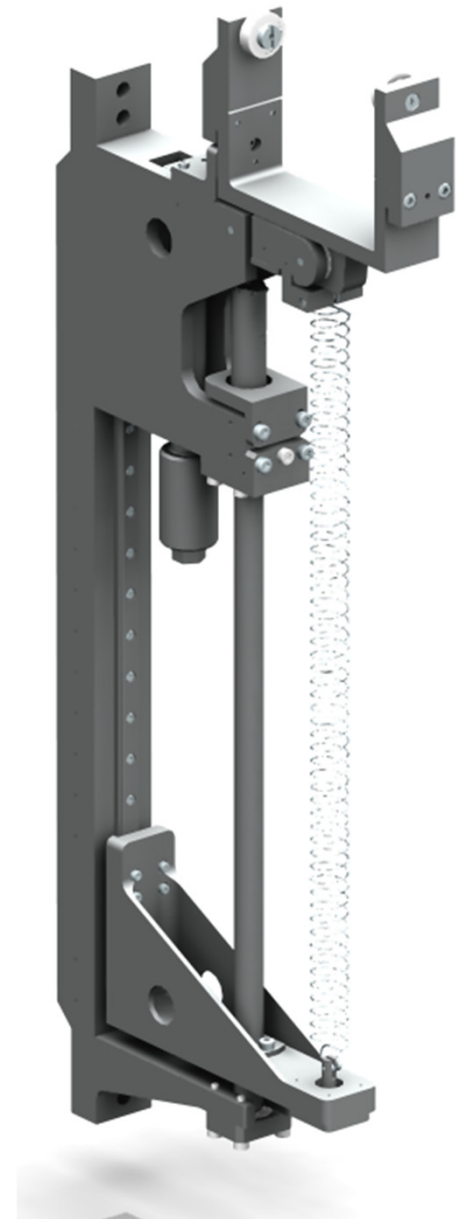


ES P201631142
ES P201630506
ES P201530735

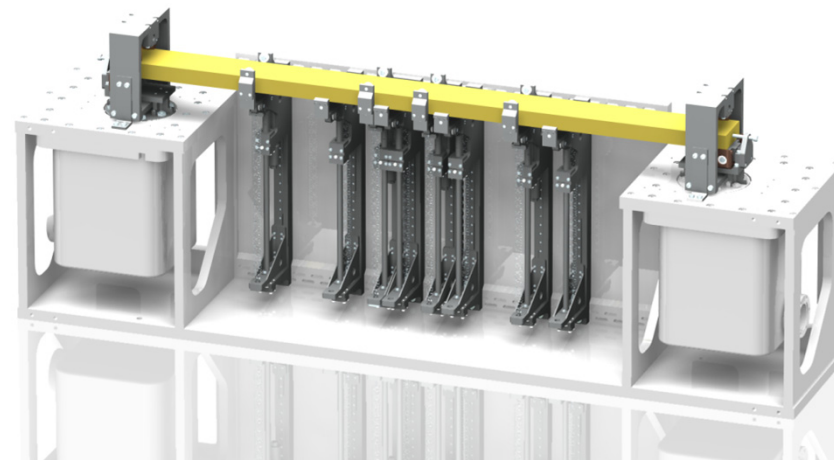


Active Optics

- *With such figure error accuracy and resolution it is possible to correct beam wavefront distortions*
- *With a double spring the corrector can switch from pusher to puller just by moving along the range.*
- *Change the Stepper motor for a UHV compatible one.*
- *mount as many correctors as space allows.*



- The proposed solution of a bender with figure correctors based in force constrains works at nanometer level
- A mirror bender with correctors without crosstalk is achieved.
- A very stable correctors have been design and implemented.
- New $-k$ compensated correctors have been designed and tested. They keep force constant within 1 mN in a range of motion of the mirror up to 2 mm.
- New, frictionless, torque free articulation has been designed, and is being currently tested.



Joan Casas

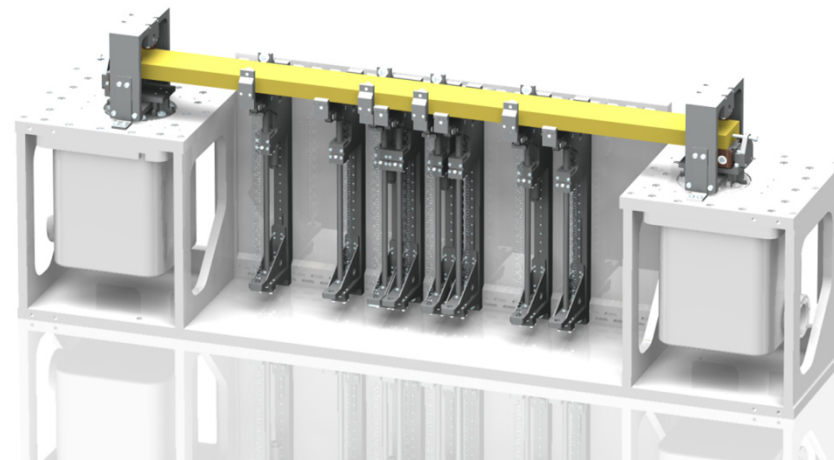
Jose Ferrer

Gabriel Peña

Llibert Ribó

Pablo Pedreira

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Thanks for your attention ...

