Optimization Method Using Thermal and Mechanical Simulations for SIRIUS High-Stability Mirrors

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Abstract

The mirrors for Sirius, the new 4th-generation synchrotron at the Brazilian Synchrotron Light Laboratory (LNLS), have strict requirements regarding thermo-mechanical stability and deformations, with figure height and slope errors limited to a few nanometers and tens of nanoradians, respectively. Therefore, fixed-shape mirrors have been defined with horizontally-reflecting orientation (except for vertically-reflecting mirrors of KB systems), whereas their cooling schemes (namely, air, water or liquid nitrogen cooling) depend on to the particular power load. A thermal and mechanical optimization method was developed to guide the design of mirrors through the evaluation of deformations caused by power load, cooling, gravity, tightening of the fastening screws and manufacturing errors and modal analyses. Two examples are presented to illustrate the method.

Sirius Mirror Systems Highlights

- Deterministic Design
- High Stability (eigenfrequencies > 150 Hz)
- Cryogenic cooling possibility with cryostat and copper straps (up to 50 W)
- Subnanometer deformation potential
- Low complexity mechanics [1]

Mirror Design Method

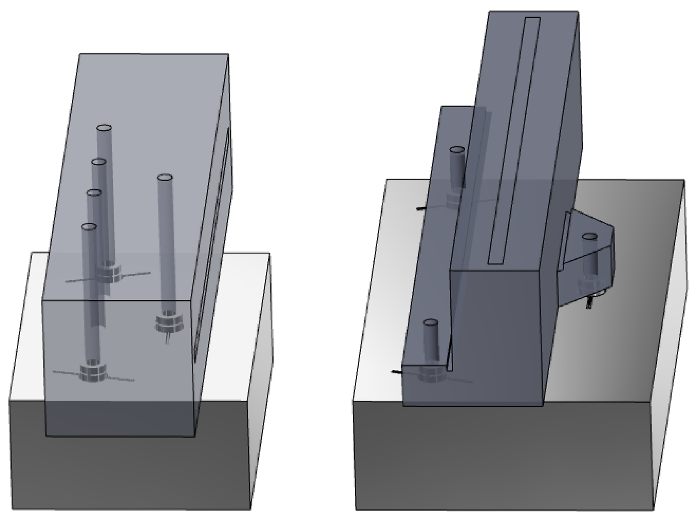
- Evaluates the deformation caused by different effects
- Optimize each effect individually
- Evaluate combined contributions and cross-check against specs

1) Get requirements from Optics Group:

Requirement	CAT-1-VFM	CAR-5-KB-VFM
Reflection Orientation	Side	Up
Figure	Cylindrical	Elliptical
Length [mm]	200	210
Power [W]	6	0
Beam Incidence Area [mm]	180x0.55	200x0.55
Peak-to-Valley Error [nm]	10	1
Height Error RMS [nm]	2.5	0.5
Slope Error RMS [nrad]	110	20

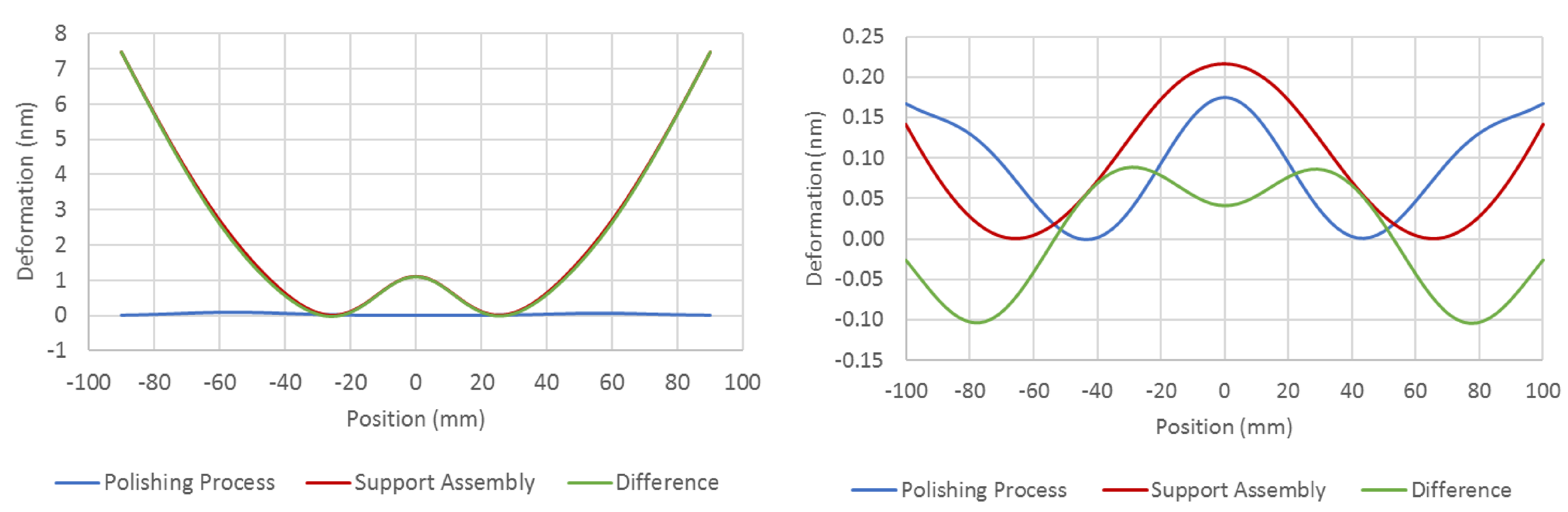
2) Define the initial shape of the mirror, taking into account:

- Mass and inertia (minimization)
- Center of gravity (stiffness lever-arms)
- Manufacturing process
- Fastening method:
  - Upper surface (lateral reflection)
  - Lateral flaps (vertical reflection)



3) Optimize the deformation curve due to fastening forces and gravity.

- As the mirror is supported in different positions in the polishing process and the assembly, the resulted curve must consider the difference between:
  - Support Assembly: Forces and Gravity (mounted on a dummy base with flexures)
  - Polishing Process: Gravity (supported as measured during the manufacturing)



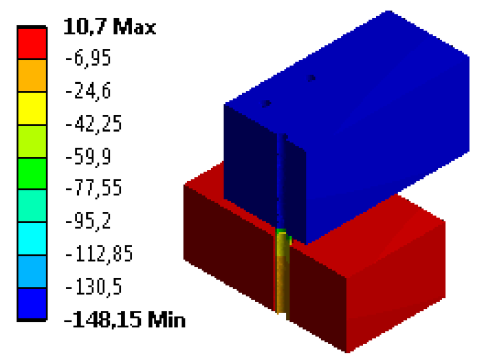
4) Verify the deformation caused by manufacturing tolerances. A gap is included between the mirror and one of the three hinges. It is done for two separate cases:

a) Gap at lateral hinge
b) Gap at central hinge

Mirror Design Method (cont.)

5) Evaluate the deformation caused only by thermal effects:

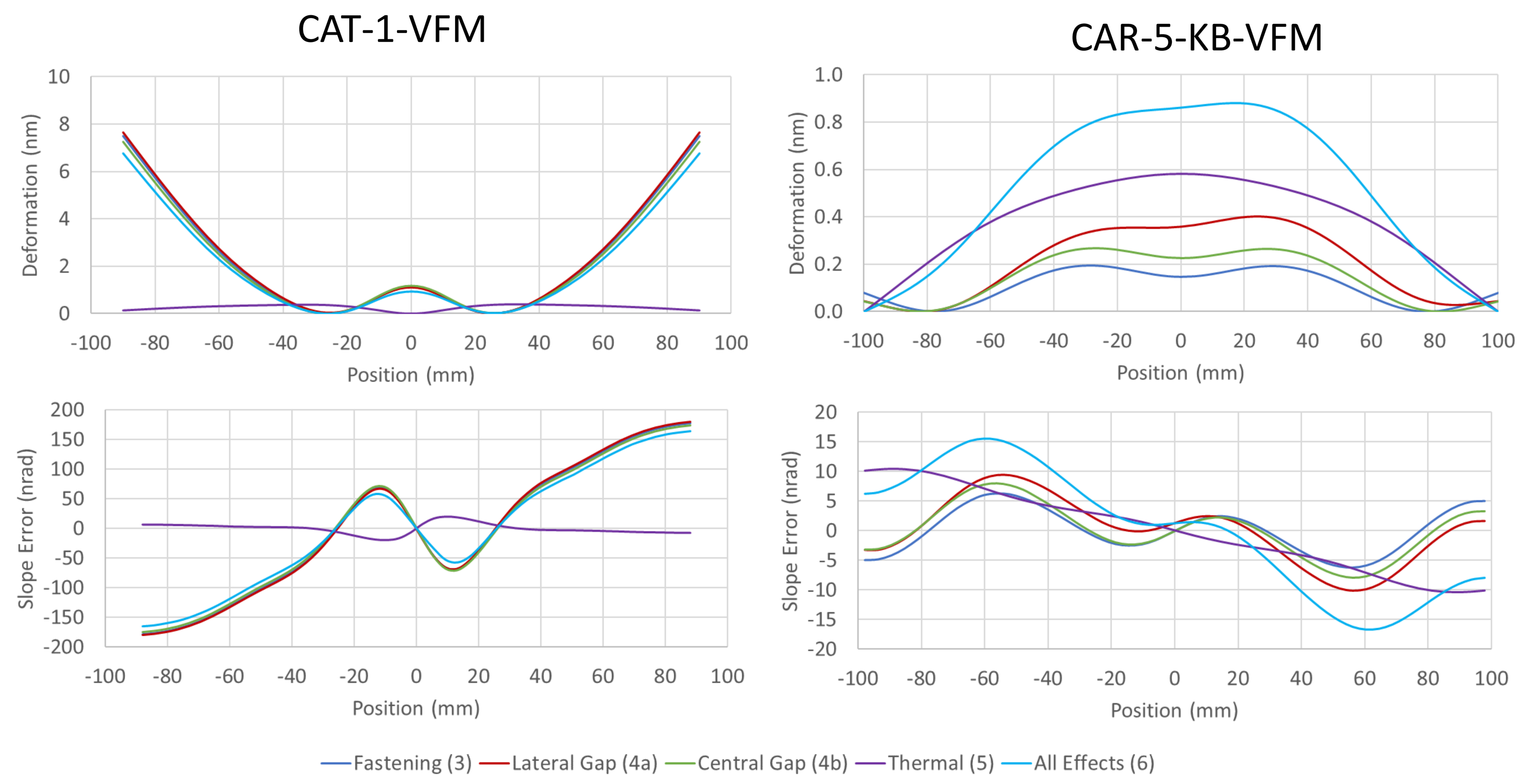
- Non-cooled mirrors: from 22°C (assembly room) to 24°C (hutch)
- Cryogenic cooled mirrors: From 22°C to 125 K (mirror) and to 10.7°C (support), with beam power included.



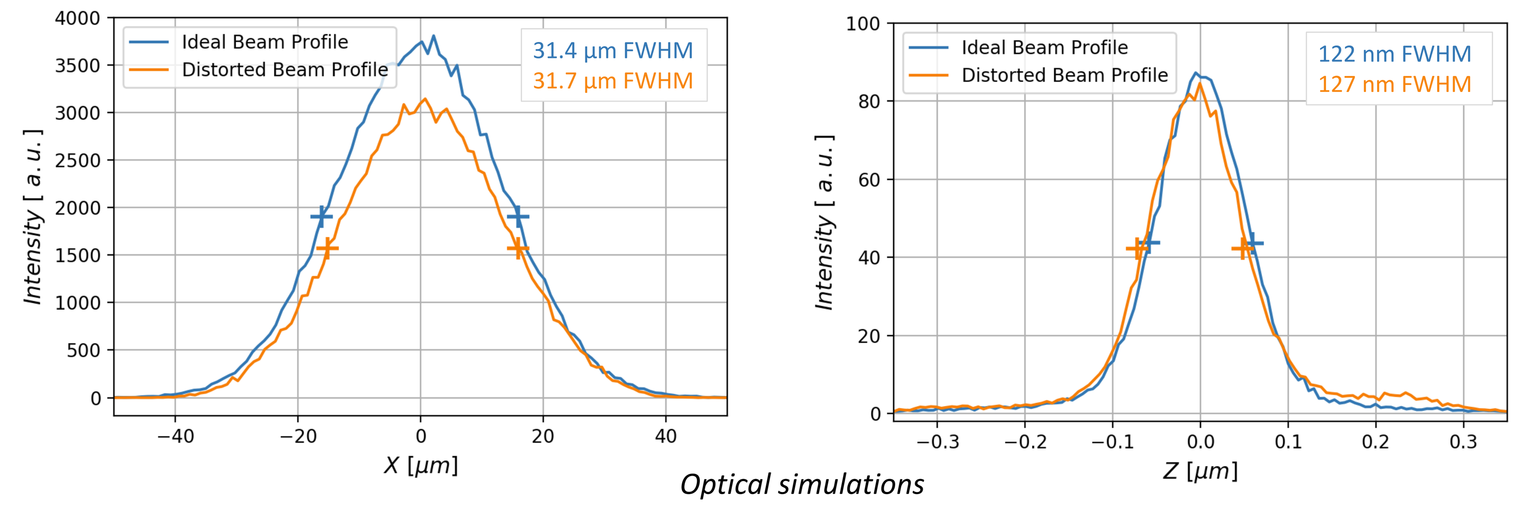
CAT-1-VFM Thermal Simulation

6) Perform a final deformation simulation including all effects (gravity, force, tolerance, thermal):

- Deformation expected in operating conditions
- Optical simulation to verify the photon beam profile quality



Deformation and slope error curves



Optical simulations

7) Modal analysis:

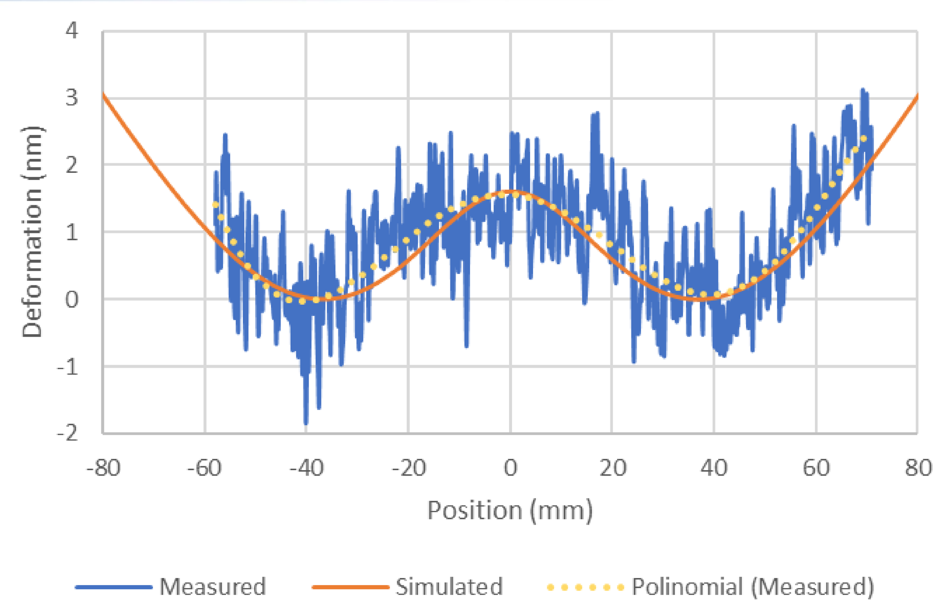
- First eigenfrequency greater than 300 Hz to guarantee at least 150 Hz on complete system

Results Table

Requirement	CAT-1-VFM		CAR-5-KB-VFM	
	Result	Criteria	Result	Criteria
Peak-to-Valley Error [nm]	6.8	< 10	0.88	< 1.0
Height Error RMS [nm]	2.0	< 2.5	0.31	< 0.5
Slope Error RMS [nrad]	101	< 110	10.4	< 20
Eigenfrequency - 1st mode [Hz]	571	> 300	969	> 300

Validation

Comparison between simulated result and a measurement made on the CAR-1-MC mirror, using the Fizeau Zygo Dynafiz, for the mirror supported on a base with the fastening force.



References

[1] R.R. Geraldes et al., "The Design of Sirius X-Ray Mirror Systems", presented at MEDSI'18, Paris, France, Jun. 2018, this conference.

MEDSI PARIS 2018
MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION
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