The Nano-Optic-Measuring Machine - NOM -

Characterisation

of the NOM as the prototype for a high precision measurement machine for plane and low curved optical surfaces.

A new development by
Berliner Elektronenspeicherringgesellschaft mbH
- BESSY -
Berlin-Adlershof , Germany
Albert-Einstein-Strasse 15, D 12489 Berlin.

Presented by
OEG GmbH
Frankfurt (Oder), Germany

September 8, 2005

The Nano-Optic-Measuring Machine - NOM -

The NOM is a non-contact deflectrometry sub-nm topography measuring machine for highest precision optical surfaces like EUV or Synchrotron Radiation application

NOM-principle

◆ Hybrid system with two deflectometry sensors
(Long Trace Profiler LTP and Autocollimator AKF) on the same machine base

◆ Comparison of the systematic measuring deviations
of the both measuring channels LTP and AKF

◆Reduction of the measuring parameters
To only two base measuring parameters: length and angle,
consequently no reference surface like interference principle is necessary

◆ Highest accuracy for the mooved components

◆ Lovest influences of the invironmental factors

◆Systematical measuring deviations are extensive ascertainable and manageable

◆ The low not ascertainable systematical deviations are extensive
reduced partially with help of measuring strategies

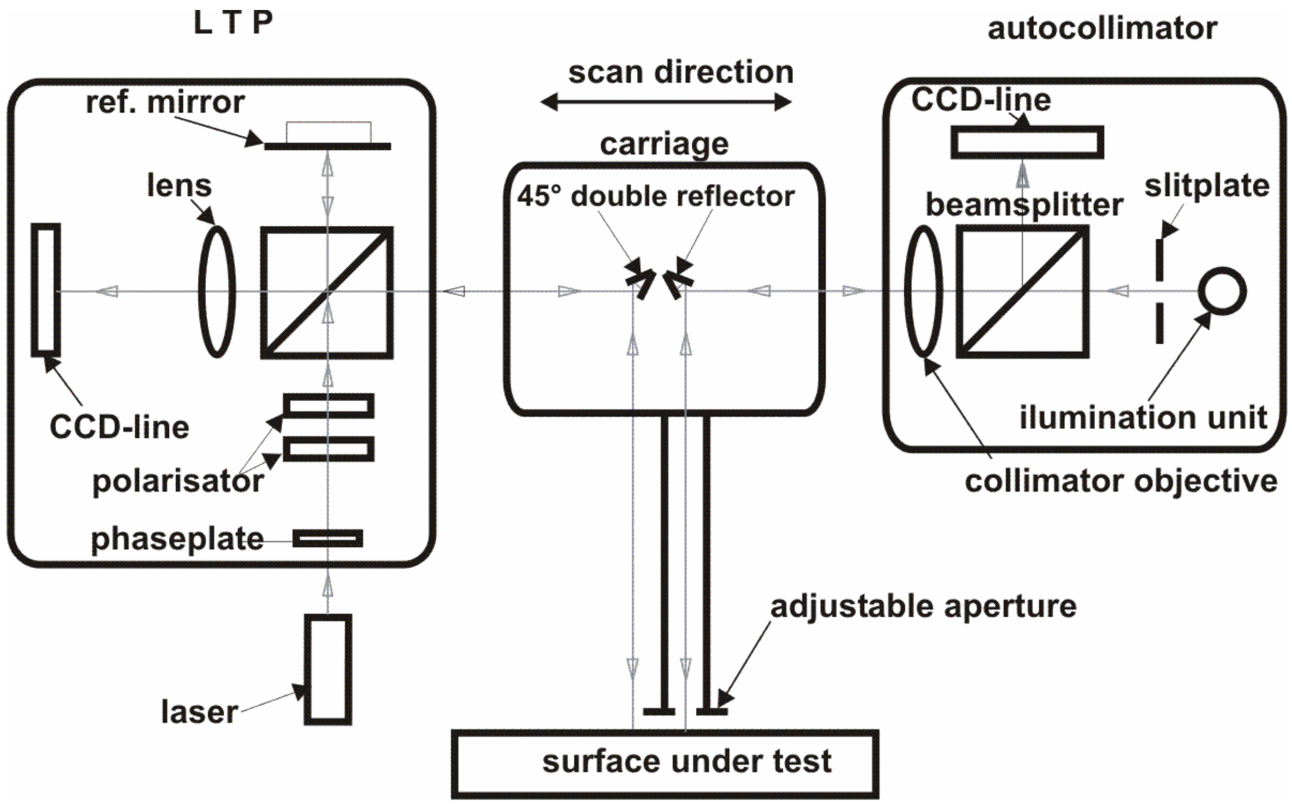
◆ Randomise measuring deviations are very low
by optimisation of the internal and external error sources,
such as noises, drifts, movement deviations,
and furthermore reduceable through complete automatisation

Main attributes of the NOM

1. Accuracy: 10 marcsec rms; < 0,5 nm rms, reproducibility < 0,05 nm/200 mm
2. 3-D-Profilometry of the whole measured surface
3. Presently NOM is a prototype of a measuring machine with industry-like meashuring times

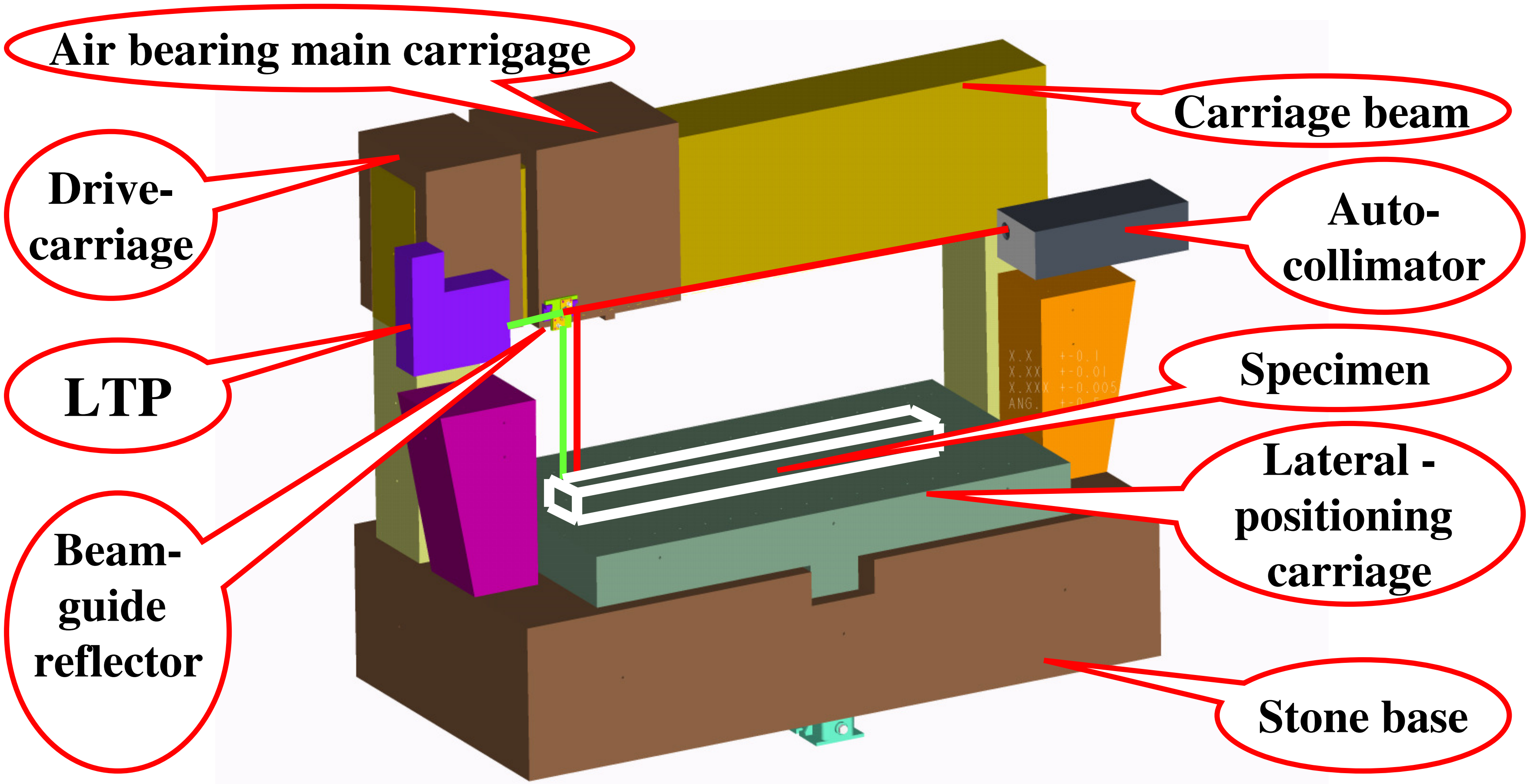
The Nano-Optic-Measuring Machine - NOM -

Optical set-up scheme of the NOM (front view)



The Nanometer-Optical-Measurement Machine - NOM -

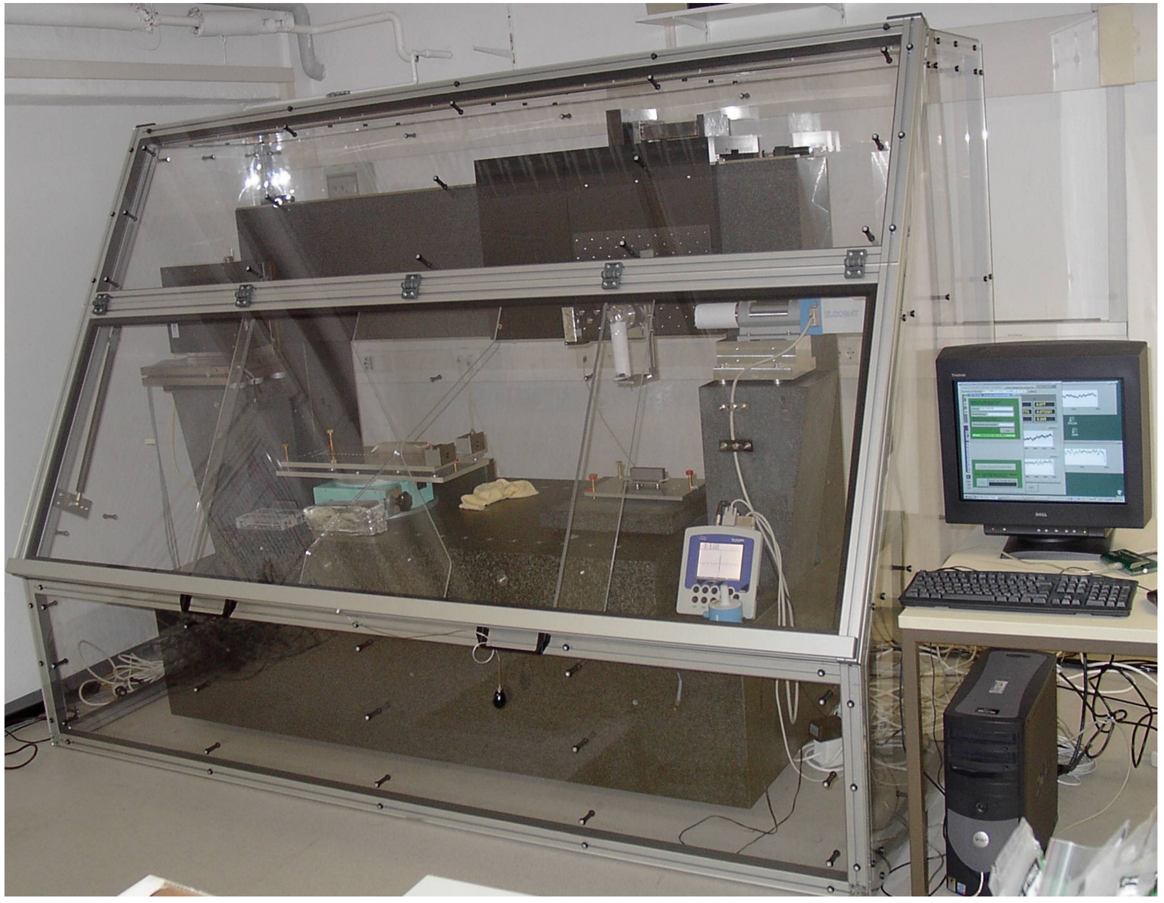
a non-contact deflectrometry sub-nm topography measuring machine for highest precision optical surfaces like EUV or Synchrotron Radiation application



Stone Table and Carriage System with aerostatic bearings

The Nano-Optic-Measuring Machine - NOM -

The Prototype of the machine at BESSY - Berlin



- **material**
  of main mechanical parts:

stone
  - high heat capacity
  - low thermal conductivity
  - low coefficient of thermal expansion
  - sluggish response due to thermal change
  - physically stable

- **total weight**: 4t
  - low eigenfrequency - vibration damping

- **scanning unit** - low weight
- **double carriage system** linked by a torque free coupling

Technical Parameters of the NOM

Measuring area: 1200 mm in length, 300 mm (600 mm) laterally

Accuracy of guidance of the scanning carriage: < 1 µm

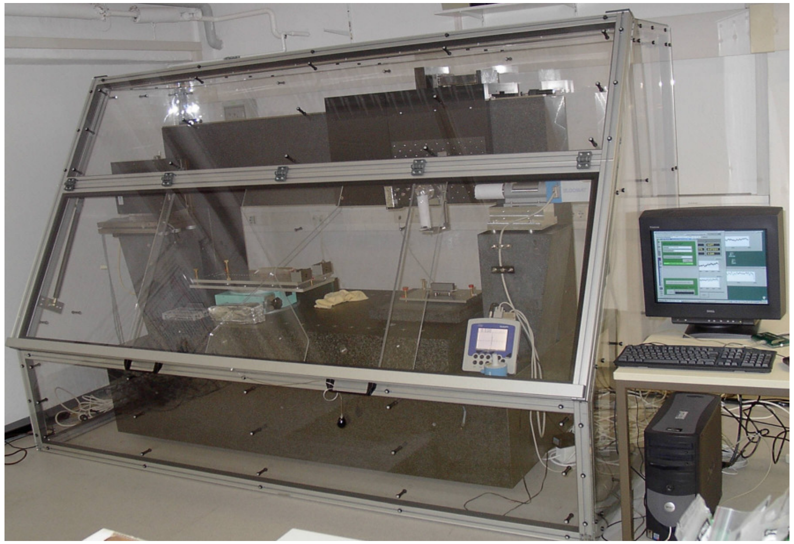
Reproducibility of the scanning carriage movement:
< 0.01 arcsec rms; < 0.2 nm rms

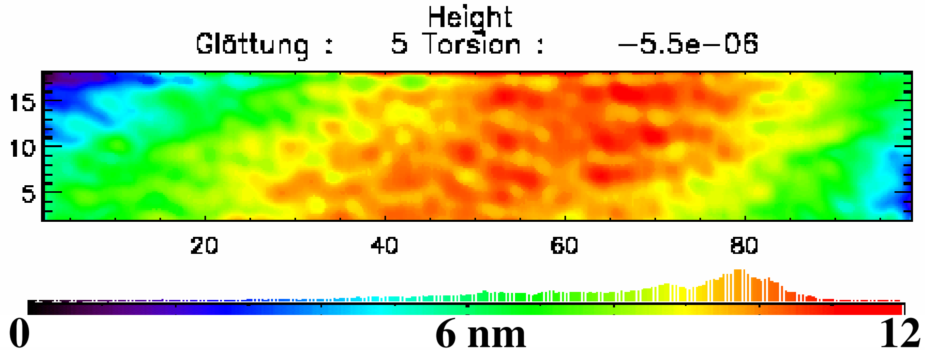
Technical Parameters of the NOM-Sensors

	Long Trace Profiler LTP	Autocollimator AKF
Viewing angle	± 6.6 mrad	± 6.6 mrad
Measurable radius of curvature	1 m	10 m
Spatial resolution	>/= 1 mm	>/= 2 mm
Footprint	1 mm	1.5 - 5 mm
Reflectance	4 - 100 %	4 - 100 %

The Nanometer-Optical-Measurement Machine - NOM -

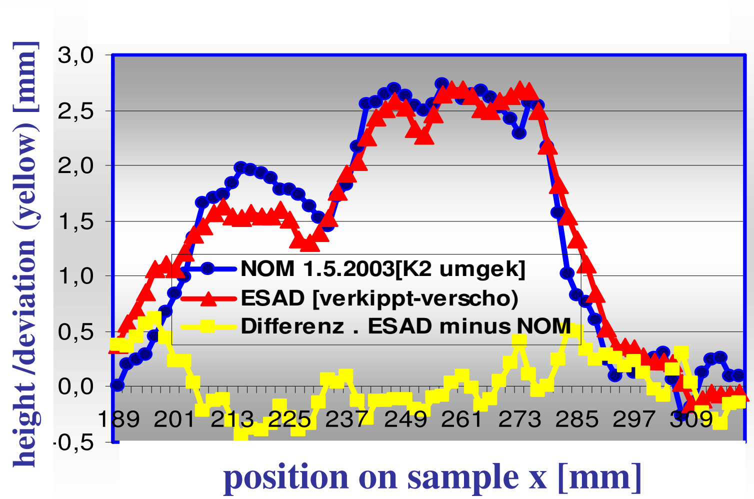
a non-contact deflectometry sub-nm topography measuring device for X-ray optics





3D-mapping with reproducibility < 0.1 nm rms

Reproducibility of a 480 mm measured length
< 0.3 nm rms; 0.2 marcsec rms = 1nrad rms



Comparison of two different measurements
ESAD (PTB) and NOM (BESSY)
510 mm plane mirror of 510 mm x 118 mm
with 0,02arcsec rms (best fit),
Conformity of both measurements
for the central scan-section of 130 mm:
< 0.3 nm rms

The Nano-Optic-Measuring Machine - NOM -

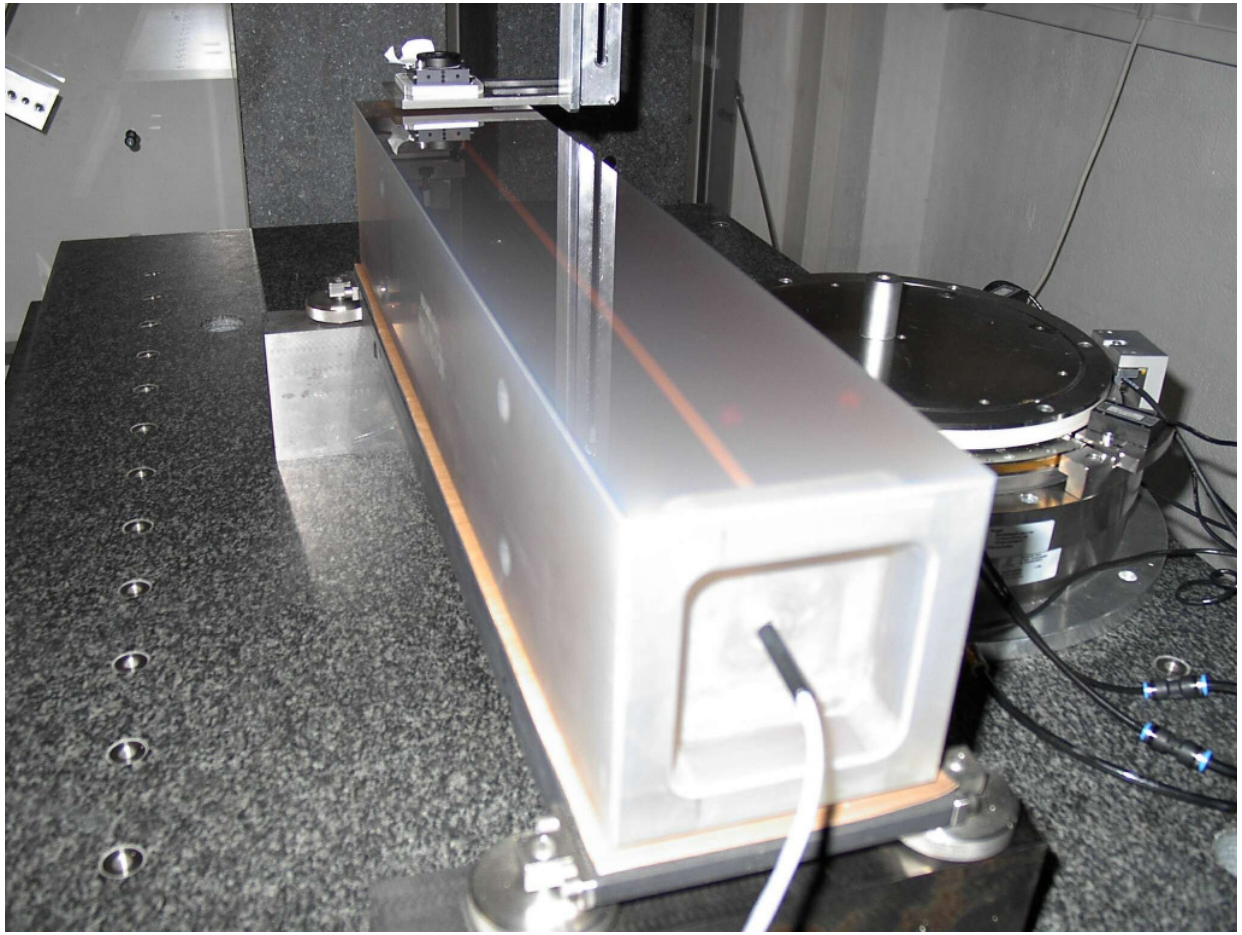
Relationship between : Measurement accuracy, Sample dimension, Required measurement times

Meas. accuracy meas. time at different plane surfaces	Samples in different dimension ranges				
Diameter [mm]:	Ø 6	Ø 50	Ø 250	Ø 500	(Ø 650)
Length [mm] x width[mm]:	20x5	100x20	**500x100**	**1000x200**	**1200x300**
surface [cm²]:	0.5	20	500	2000	3600

Measuring accuracy ranges stand.dev.97´%	Rms	peak to valley	p-v	meas. point distance mm	meas. point number 1/cm²	**Required meas. time for a plane surface in surface measurement (3-D-mapping) in automated measurement run**				
λ/25	50 nm	λ/5	120 nm	50	0,2				20 min	20 min
λ/40	15 nm	λ/8	80 nm	10	1				40 min	1 h
λ/60	10 nm	λ/12	50 nm	5	4		3 min	1 h	2 h	4 h
λ/300	2 nm	λ/60	10 nm	2	25		10 min	4 h	0.5 d	1 d
λ/1200	0.5 nm	λ/ 200	3 nm	1	220		90 min	**1 d**		
λ/2000	**0.3 nm**	**λ/600**	**1 nm**	0.4	1500	**20 min**	**8 h**			

BESSY

Line-scan on a 510mm mirror - substrate material: Zerodur™



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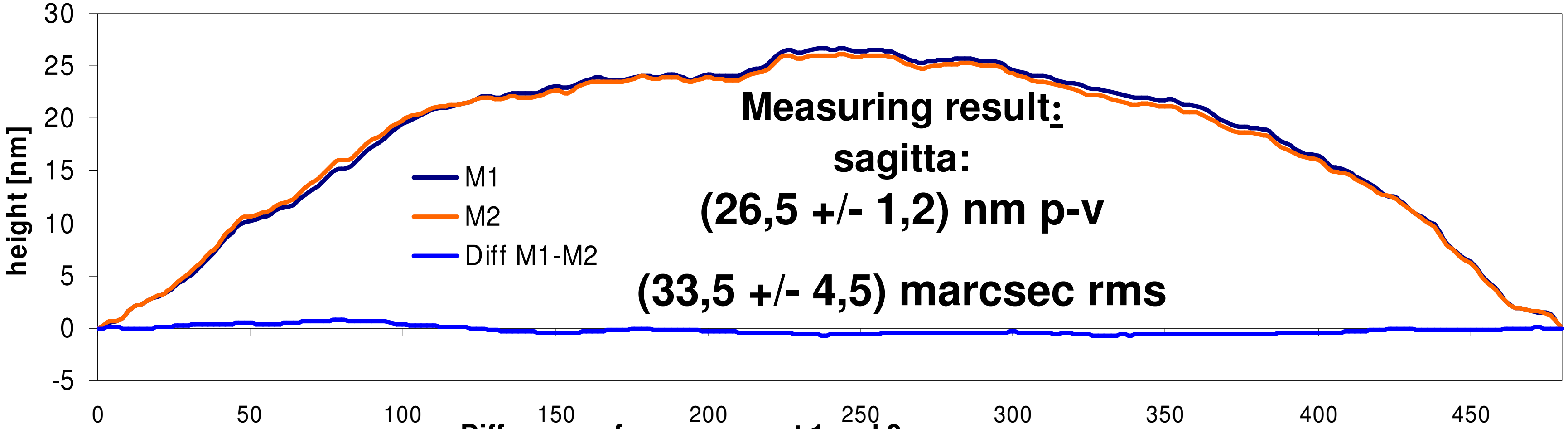
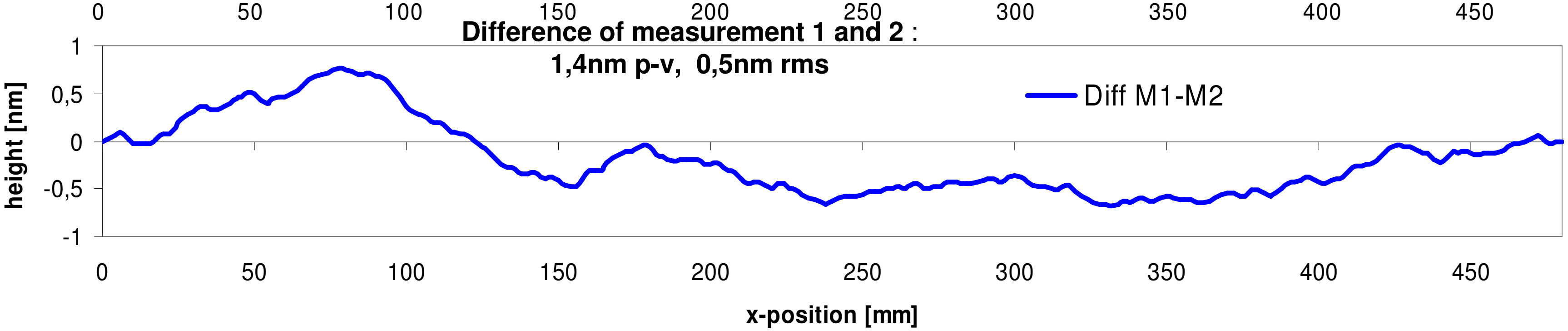
NOM (AKF)- Measuring result Zerodur™-specimen 510 mm - Reproducibility



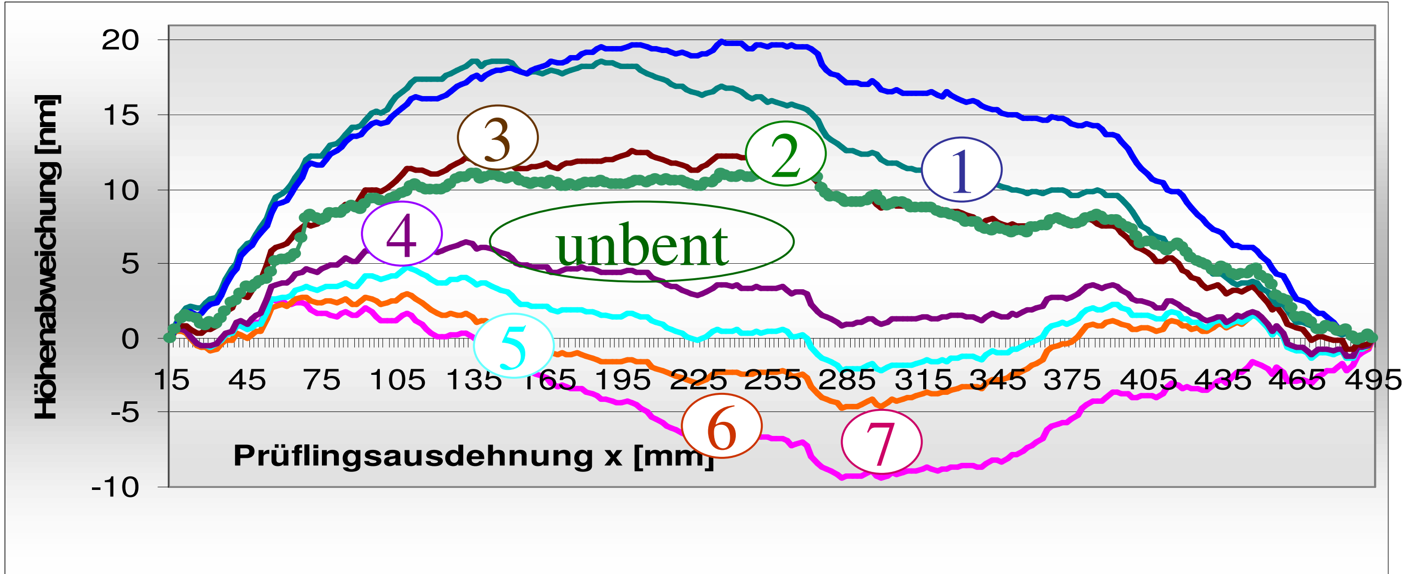


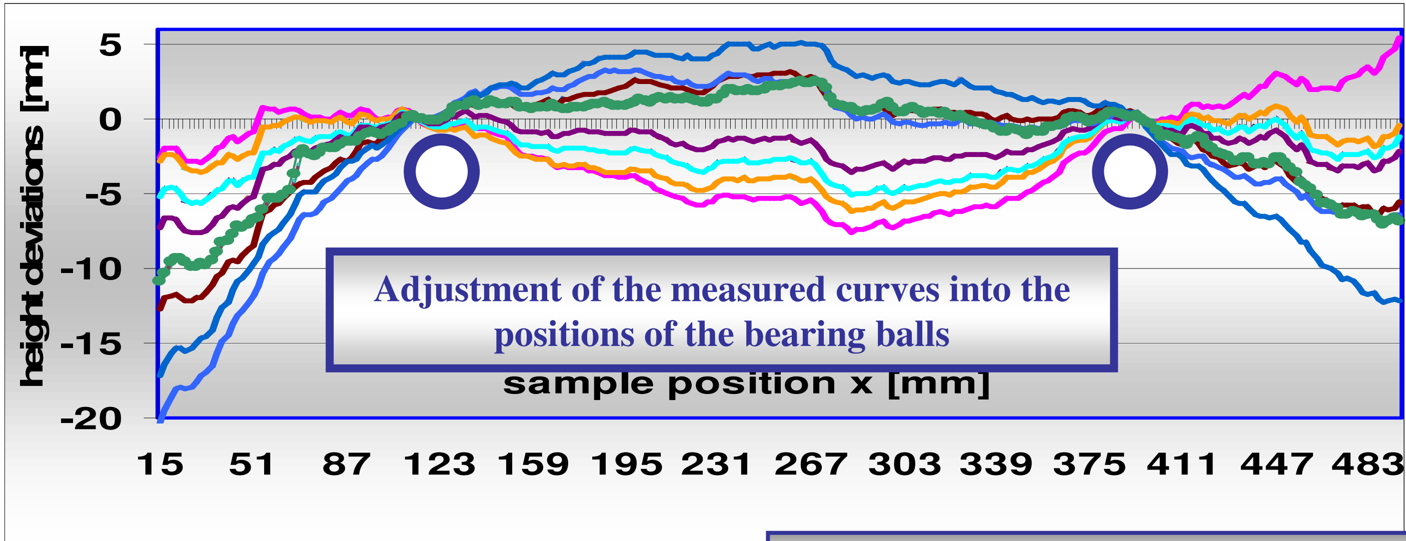
Radius: **- 1083 km;**
residual height: **4,4 nm p-v**
residual slope: **20,4 marcsec rms**
= 98 nrad rms (spatial resolution 5 mm)

Reproducibility (480 mm)
< 0.5 nm rms;
0,2 marcsec rms = 1nrad rms

BESSY

NOM-Example: Bending of Zerodur mirror of 510 mm x 110 mm at defined 4-ball-support during a time sequence of 14 days as result of temprerature differences of 0,09 mK/min = 0.9 K/week



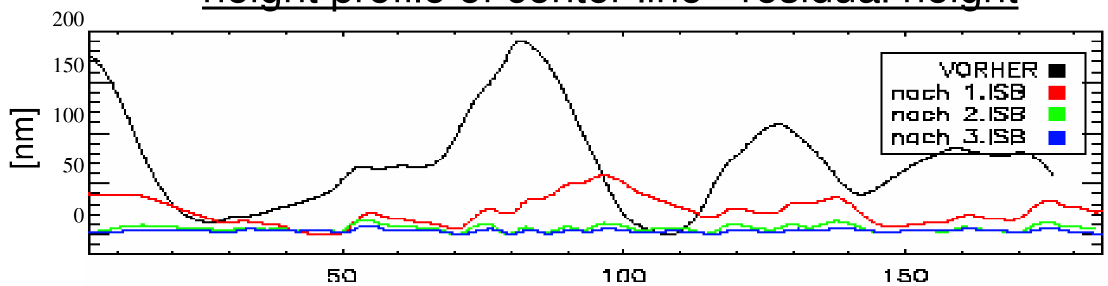


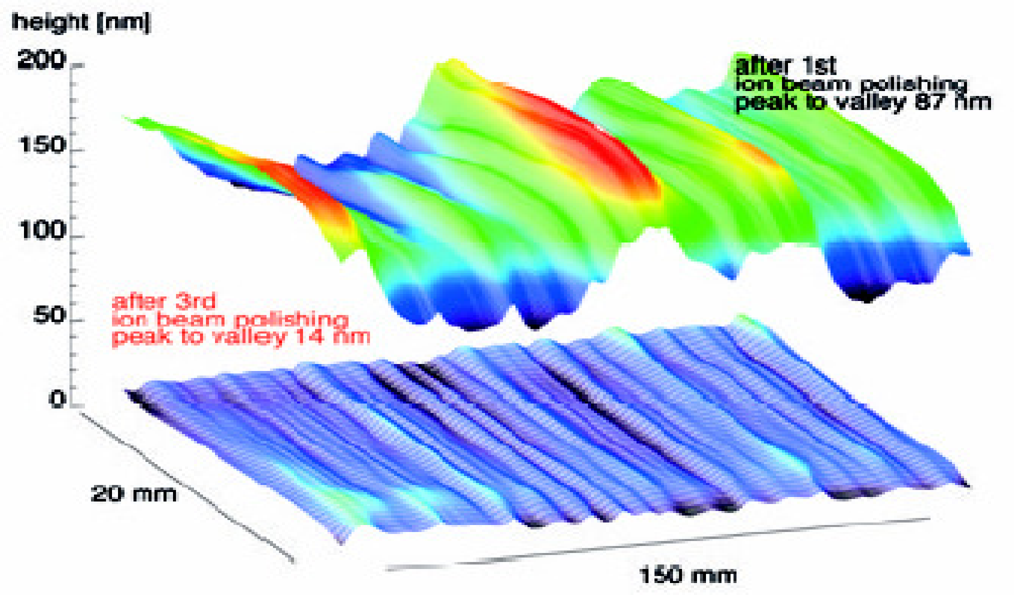
Measure-
ment
results
for
7 different
serial stress
conditions

BESSY

Measuring control by the NOM:
Ion Beam Finishing of a plane-elliptical refocussing mirror
- Progress in shape optimization by 3 iterations of IBF -

height profile of center line - residual height





	height pv	rms
initial state:	191 nm	47.3 nm
1st IBF:	58 nm	13.3 nm
2nd IBF:	14 nm	2.9 nm
3rd IBF:	9 nm	1.4 nm

residual height at optical active area:

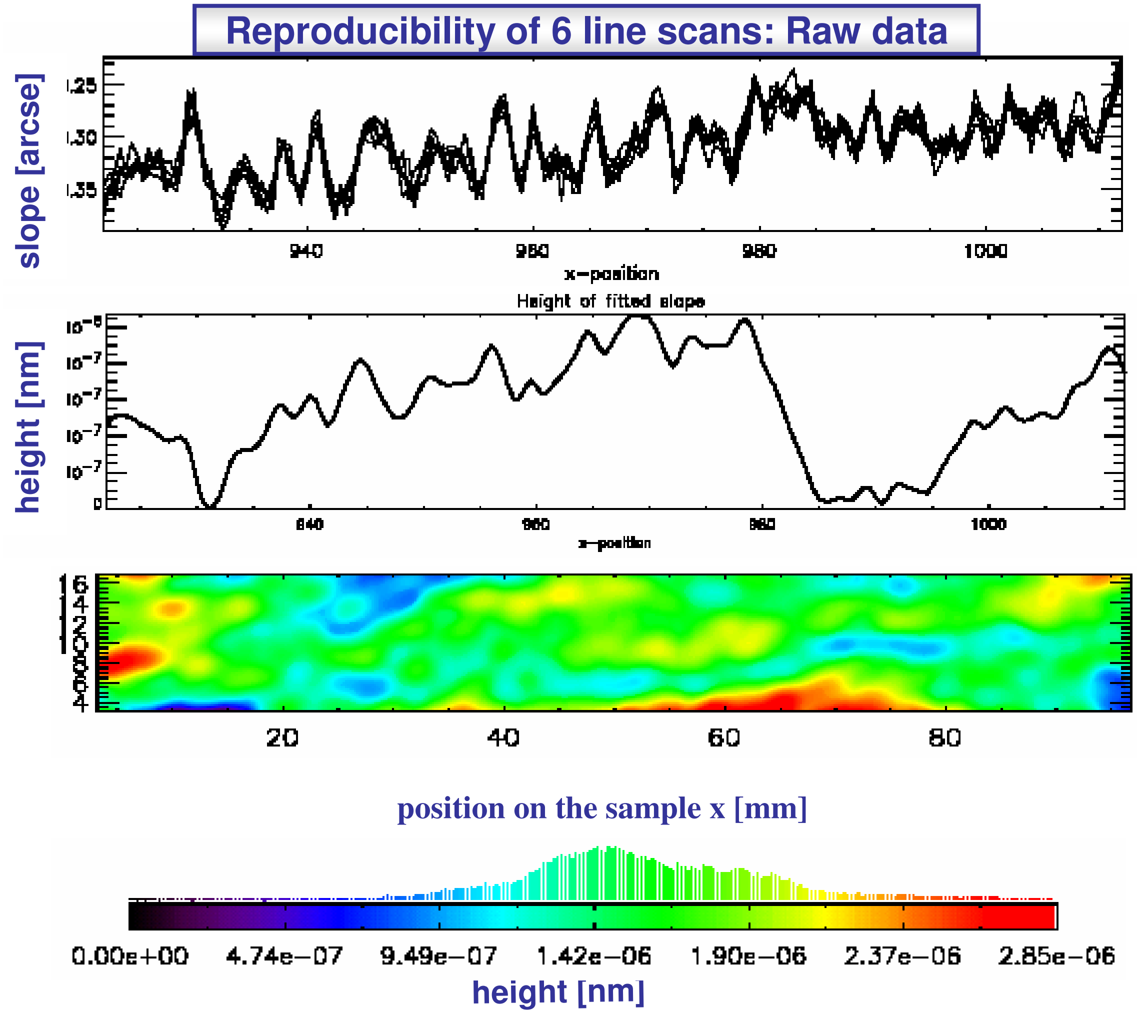
- 1st IBF: 87 nm
- 3rd IBF: 14 nm

slope [arcsec rms]

- initial state: 1.21
- 1st IBF: 0.26
- **3rd IBF: 0.14**

What accuracy can be optained by the combination NOM - IBF ?

Example: plane grating substrate 100 mm x 20 mm with extremly high accuracy



slope error fit
0.022 arcsec rms
radius: 300 km

height without fit
0.14 arcsec p-v
4 nm p-v, 1 nm rms

height fit line
1.1 nm p-v
0.28 nm rms

height fit map
2.8 nm p-v
0.35 nm rms

slope fit map
0.021 arcsec rms
l. rad.: -350 km

The measurement technique with the NOM is an outrider of the optics technology development

Perspective

The new standards of accuracy may be applied for hitherto unattainable goals:

1. • mirror and grating substrates of 0.02 arcsec rms (< 0.5 nm rms)
2. • adaptive mirrors < 0.1 arcsec rms (1 nm rms)
3. • mechanical influence of the mounting systems below 0.1 arcsec rms
4. • determination of thickness constancy of coatings to less than 1 nm
5. • radius determination of test glasses to < 0.01 %
6. • reference normal specimen for interferometry with subnanometer accuracy ($\lambda/1000$ and less)
7. • plane surface measurements with radii > 1000 km
8. • determination of long term shape stability of optical materials in the nm or subnanometer range
9. • determination of inhomogenities in optical glasses in the range of $\Delta n < 10^{-6}$

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