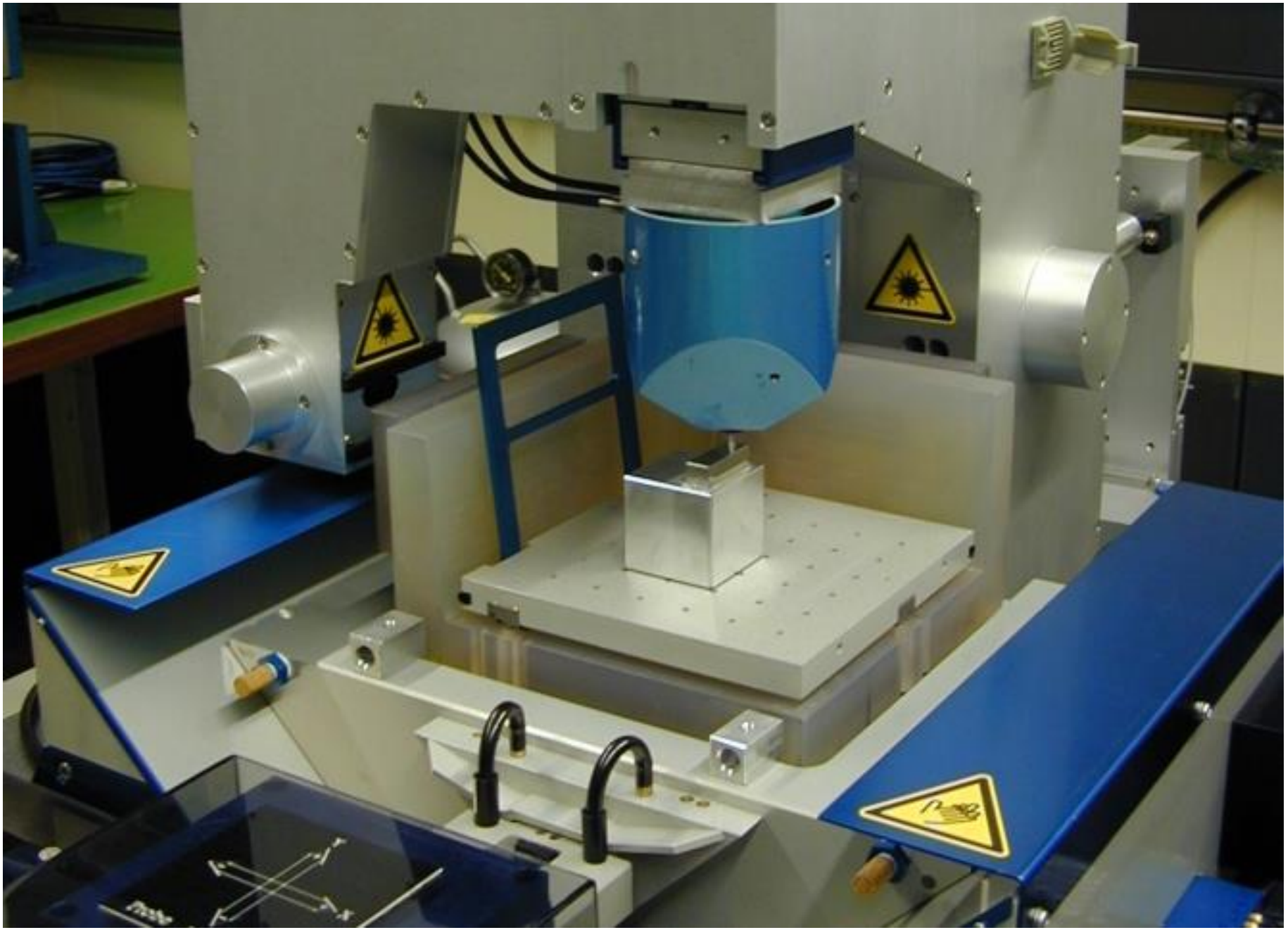
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Justice and Police FDJP
Federal Office of Metrology METAS

Traceable measurements on µicro-parts

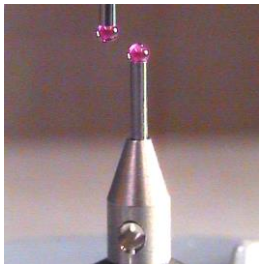
Dr. Alain Küng, Dr. Felix Meli & Dr. Rudolf Thalmann



Micro-CMM applications

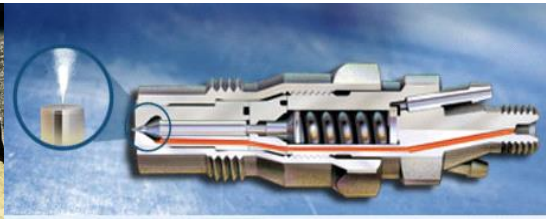
Micro-metrology:

- Precision spheres, stylus radii,
- Contour standards, rings and plugs



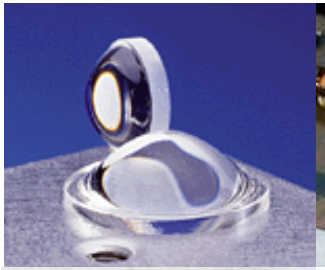
Automotive & Watch industry:

- Injection valves, cogwheels, etc…

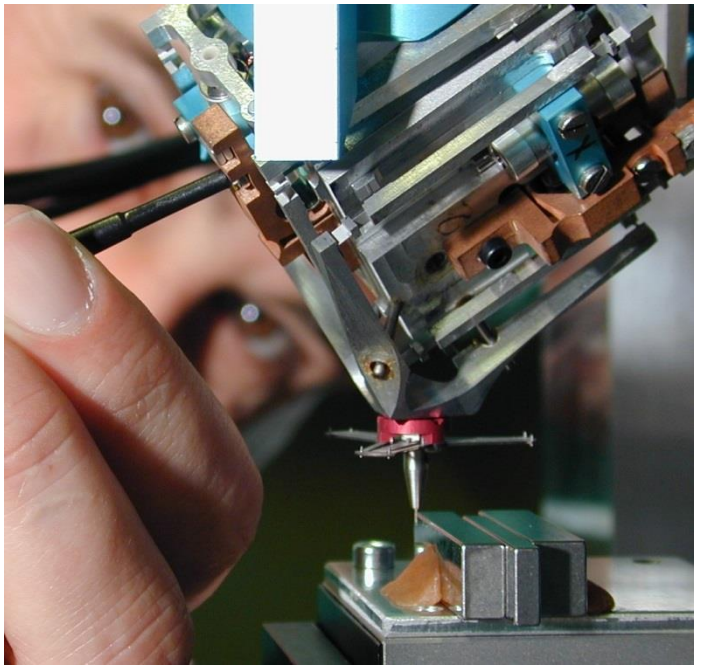


Micro-Optics, HF, Medical:

- Aspheric lenses for mobile phones,
- HF Connectors, copper parts
- Implants



Outline



The METAS

The µ-CMM design
- The probe head
- The actuator stages

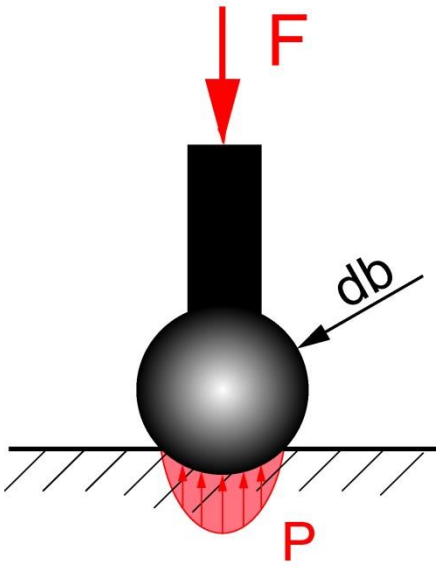
The µ-CMM calibration & acceptance test

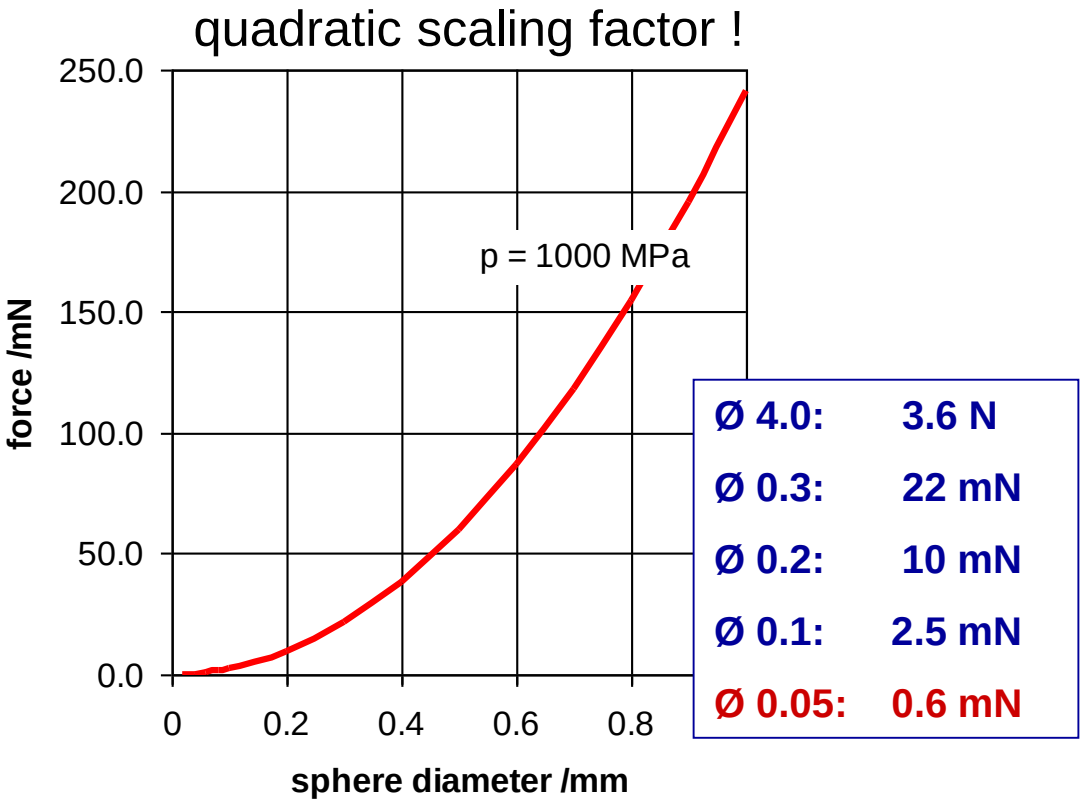
Performance from a scanning measurement

Conclusion

Critical probing forces for small diameters

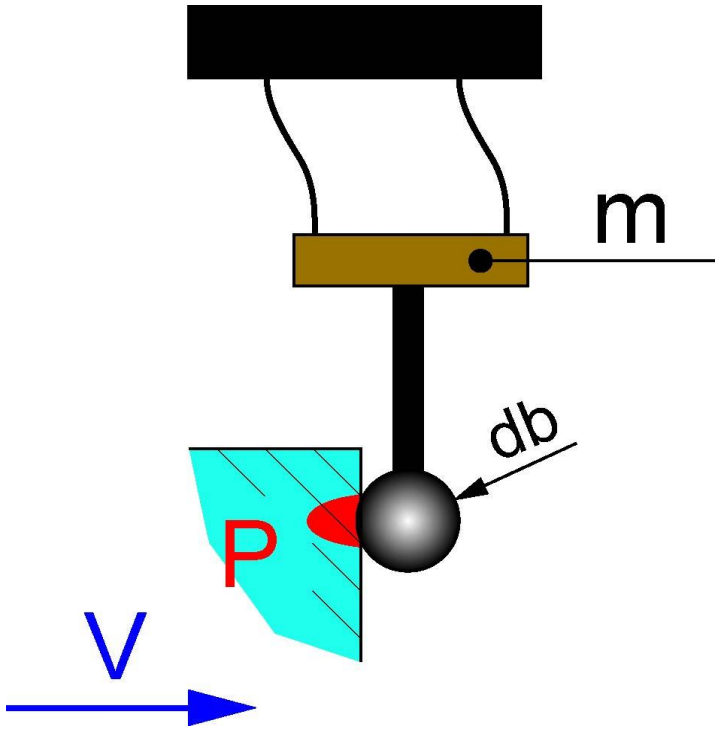
Hertz Theory: Maximum forces for 1000 MPa contact presure





Ref.: Johnson, K. L. , “Contact Mechanics”, Cambridge University Press 1985, p. 155
ISBN 0 521 25576 7

Dynamic forces



cubic scaling !

$$m = \left(13.25 \cdot \frac{Y^5}{v^2 \cdot E^{*4}} \right) \cdot db^3$$

v = approach speed

Y = tensile yield strength

E^* = equivalent Young's modulus

V = 1 mm/s:
Ø 4 mm -> m = 1.8 kg
Ø 0.2 mm -> m = 0.23 g

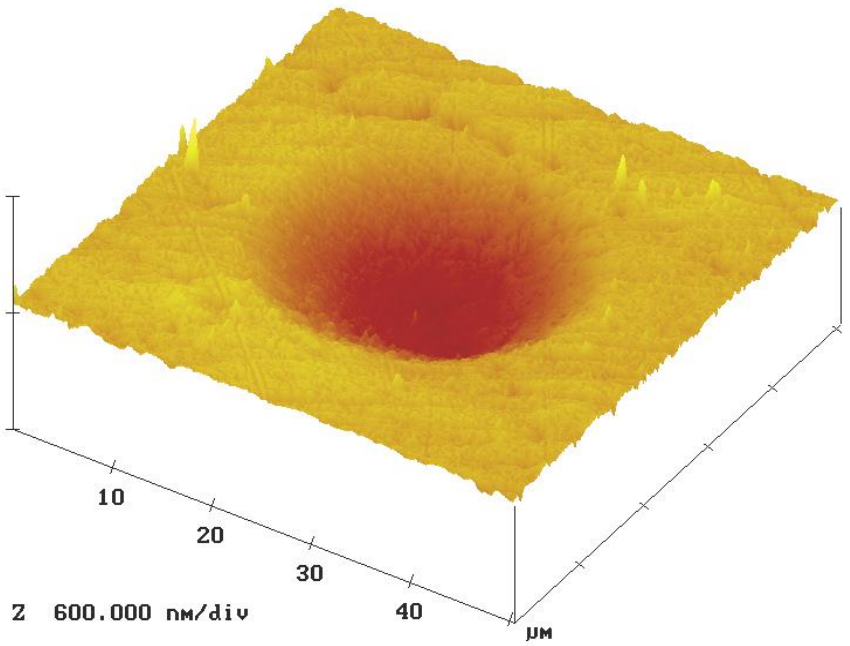
→ mass ratio 8000 !

V = 0.1 mm/s:
Ø 0.2 mm -> m = 23 g

Ø 0.10 mm -> m = 2.8 g
Ø 0.05 mm -> m = 0.35 g

Ref.: W.P. van Vliet et al., Annals of CIRP, Vol. 45/1, 1996, p. 483

Sample damages by CMM probing, aluminium

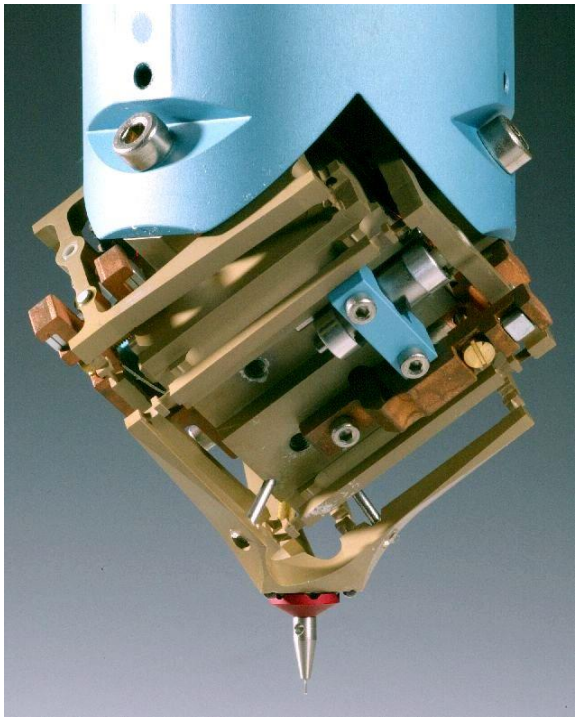


Conditions:

- conventional high end CMM with analogue probe (SIP)
- Ø 0.6 mm probe sphere

  → depth: 330 nm

3D Probe head - NanoTouch



Technical data:

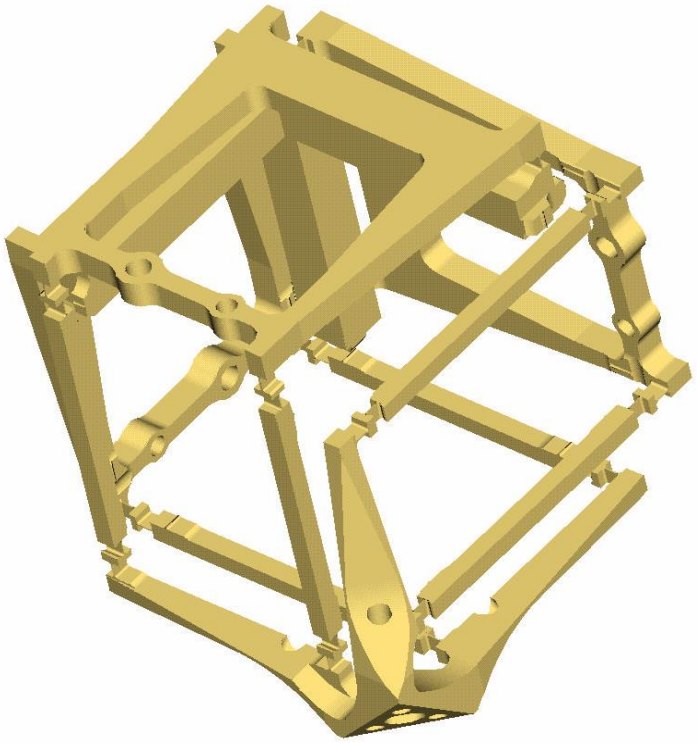
Type:	analogue 3D probe head inductive sensors robust design exchangeable probes magnetic tip holding (fuse)
Probe head range:	3 D ±150 µm
Stiffness:	26 N/m, isotropic
Typical probing force:	> 0.5 mN,
Effective mass:	7 g
Sphere diameter:	from 50 µm
Probing repeatability (1s):	5 nm, single point

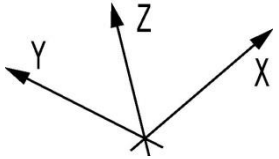
Project partners:

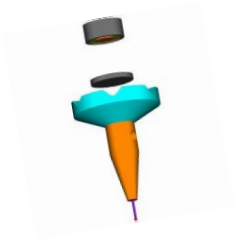
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

MECARTEX FLEXURES FOR HIGH PRECISION

The probe head design







- **Parallel cinematic**,
  3 translations (all rotations blocked)
- **60 µm** flexure hinges for very low probing forces **0.5 mN**
- 3 axes are Isotropic
- Low moving mass
- Single body, no assembly

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

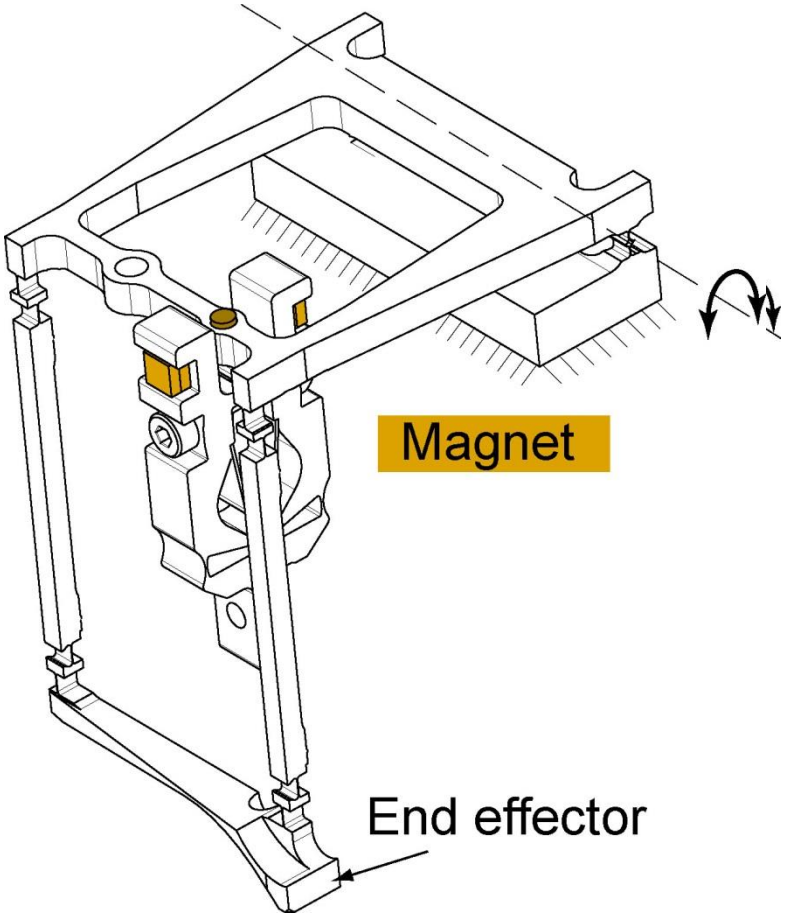
MECARTEX
FLEXURES FOR HIGH PRECISION

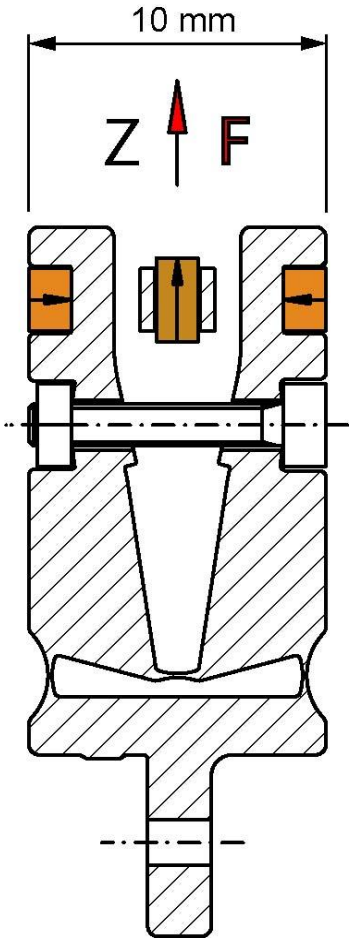
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

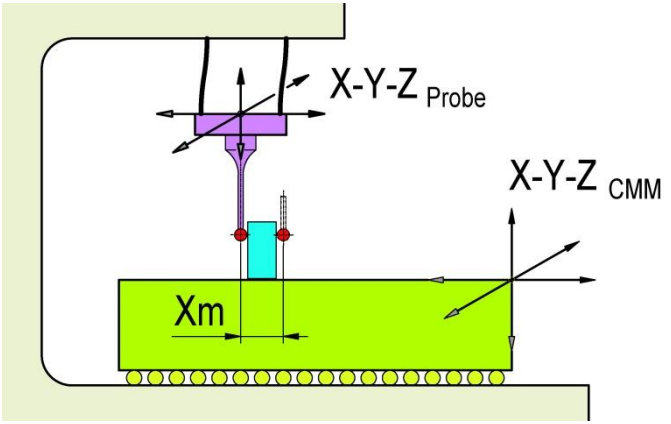
METAS

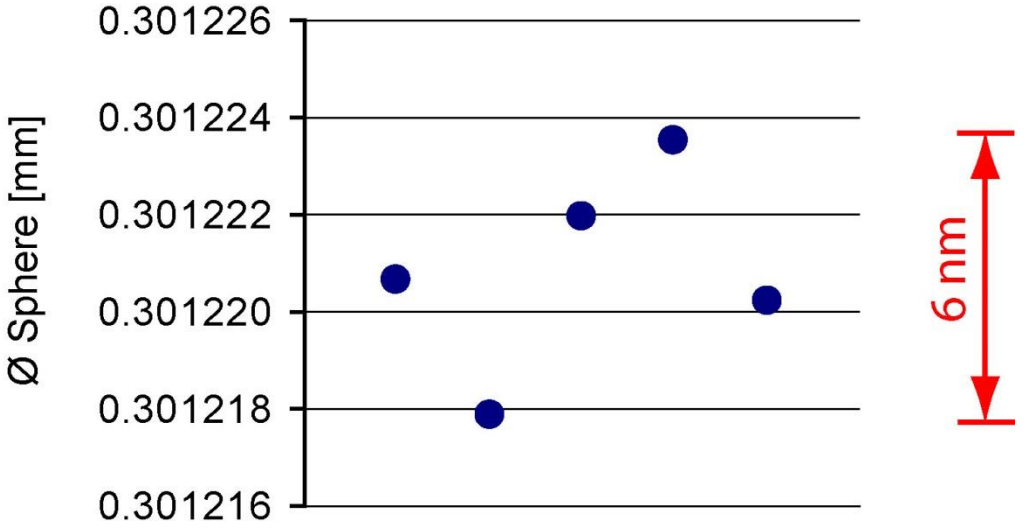
Sensors and gravity compensation

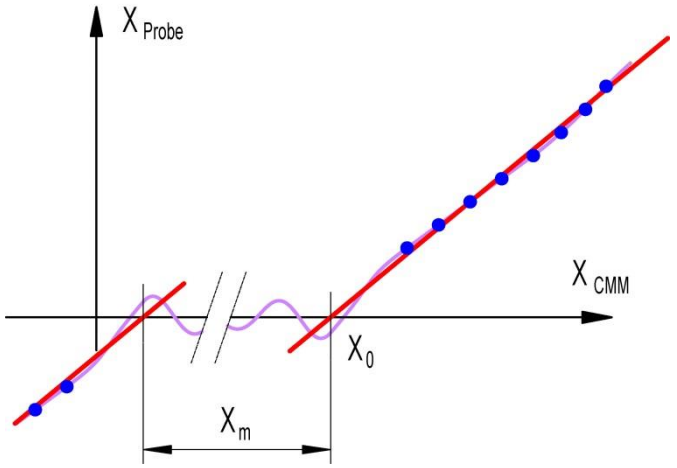




The measurement procedure

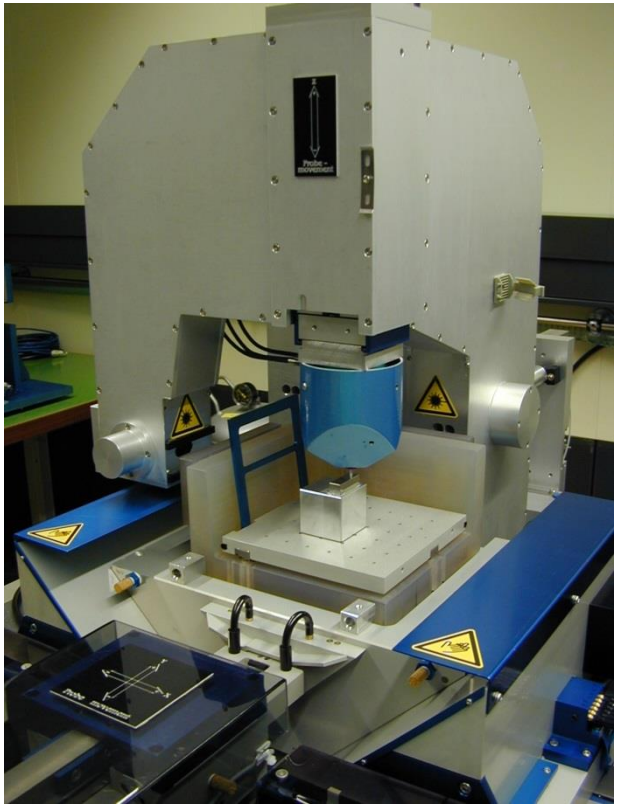




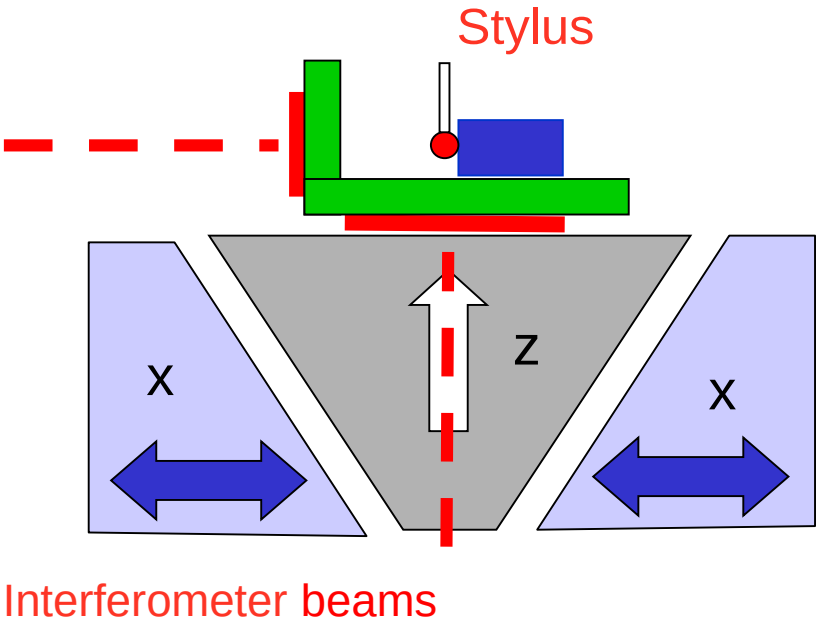


Ø sphere= Xm- gauge block length

Ultraprecision CMM stage from Philips CFT

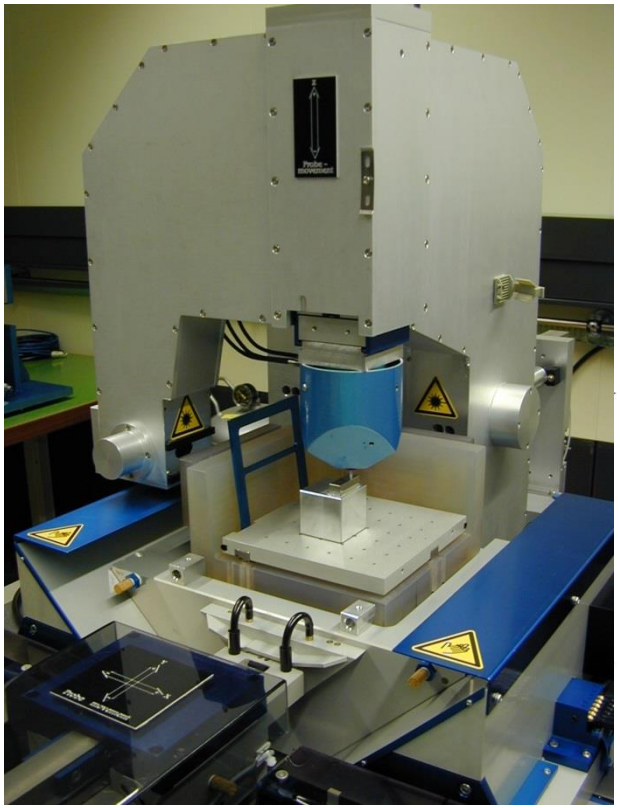


Abbe Principle:

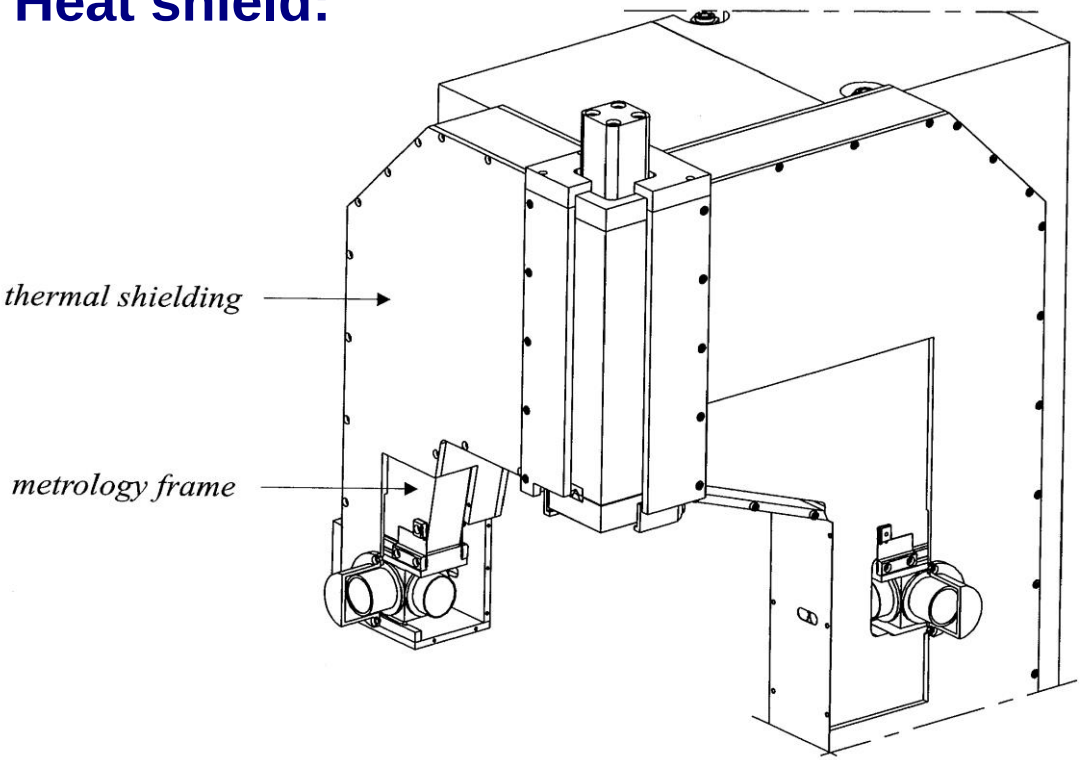


Theo Ruijl, „Ultraprecision Coordinate Measuring Machine“ Thesis, Philips CFT, Eindhoven, The Netherlands

Ultraprecision CMM stage from Philips CFT

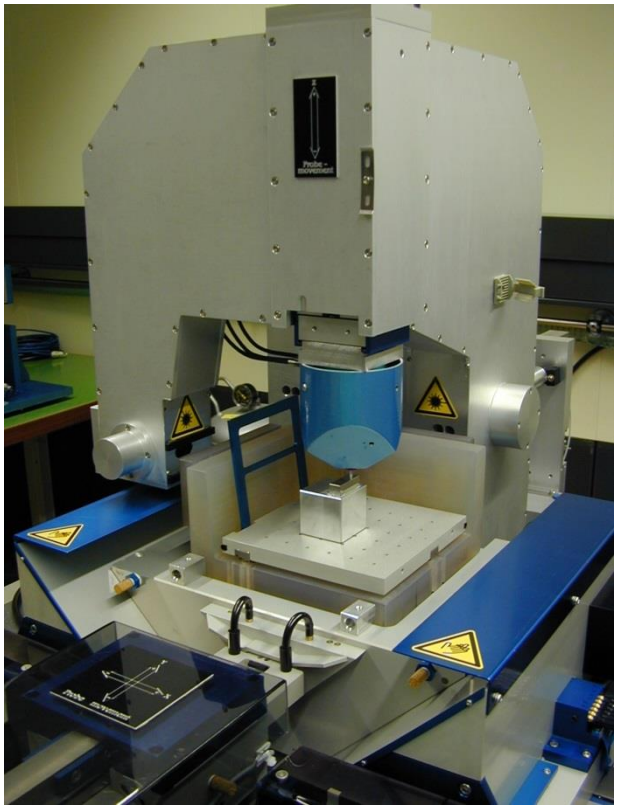


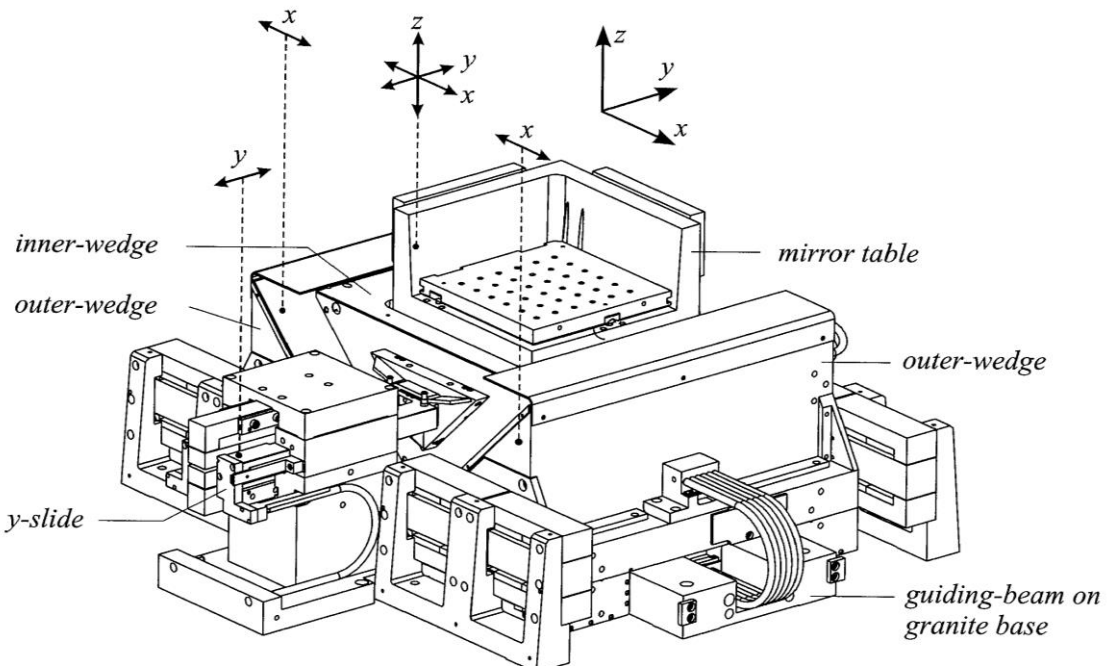
Heat shield:



Theo Ruijl, „Ultraprecision Coordinate Measuring Machine“ Thesis, Philips CFT, Eindhoven, The Netherlands

Ultraprecision CMM stage from Philips CFT





Lorenz actuators

Theo Ruijl, „Ultraprecision Coordinate Measuring Machine“ Thesis, Philips CFT, Eindhoven, The Netherlands

µ-CMM characteristic properties

Measuring volume:	80 mm x 80 mm x 40 mm
Position measurement:	3-axis Laserinterferometer, no Abbe offset
Reference system:	Zerodur cube corner with mirrors
Stage:	Vacuum air bearings
Frame:	Aluminium metrology frame
Control:	METAS LabView controller 3D track control
High level SW	QUINDOS, Leitz protocol
Operating modes:	Point probing Closed loop freeform scanning

Probing repeatability (1s): 5 nm, single point

A machine controller made in METAS

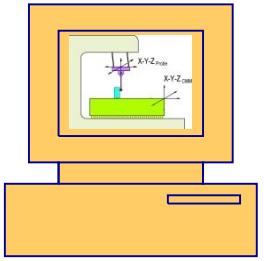
Quindos

High Level

LAN

Leitz protocol
(→ Ipp)

Machine Controller



LabView

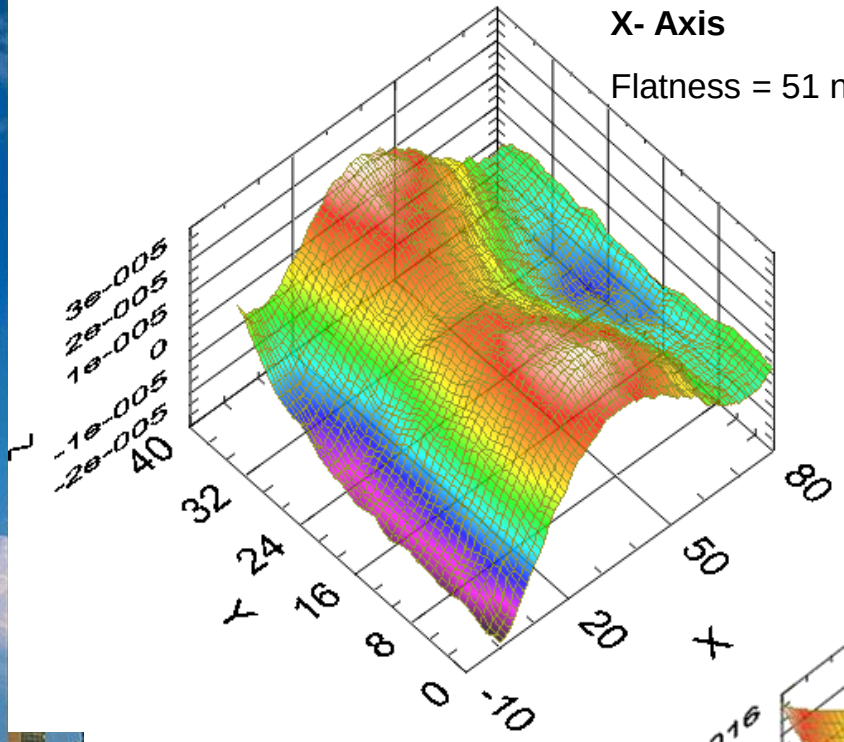
- HP Interferometer Boards (ISA)
- 3-axis motion control (PCI)
- Stage gravity compensation
- Probe head interface (PXI)
- Refraction Index (p, T_{air}, H_{rel}, CO_2)
- Material and Frame Temperatures
- Joystick
- Security and resources

error corrections → metrology know how

Flatness correction of the reference mirrors

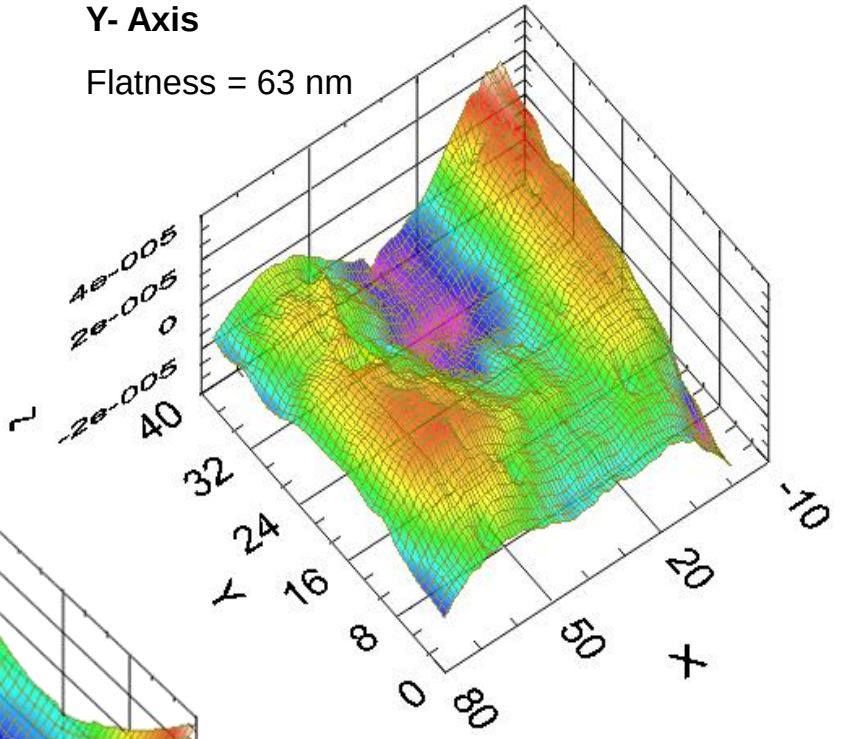
X- Axis

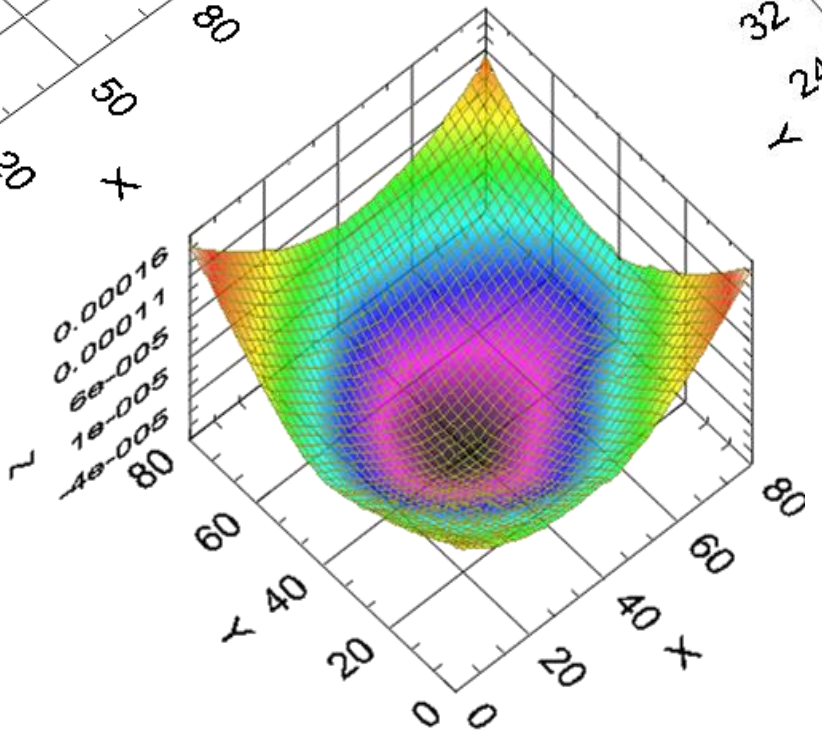
Flatness = 51 nm



Y- Axis

Flatness = 63 nm

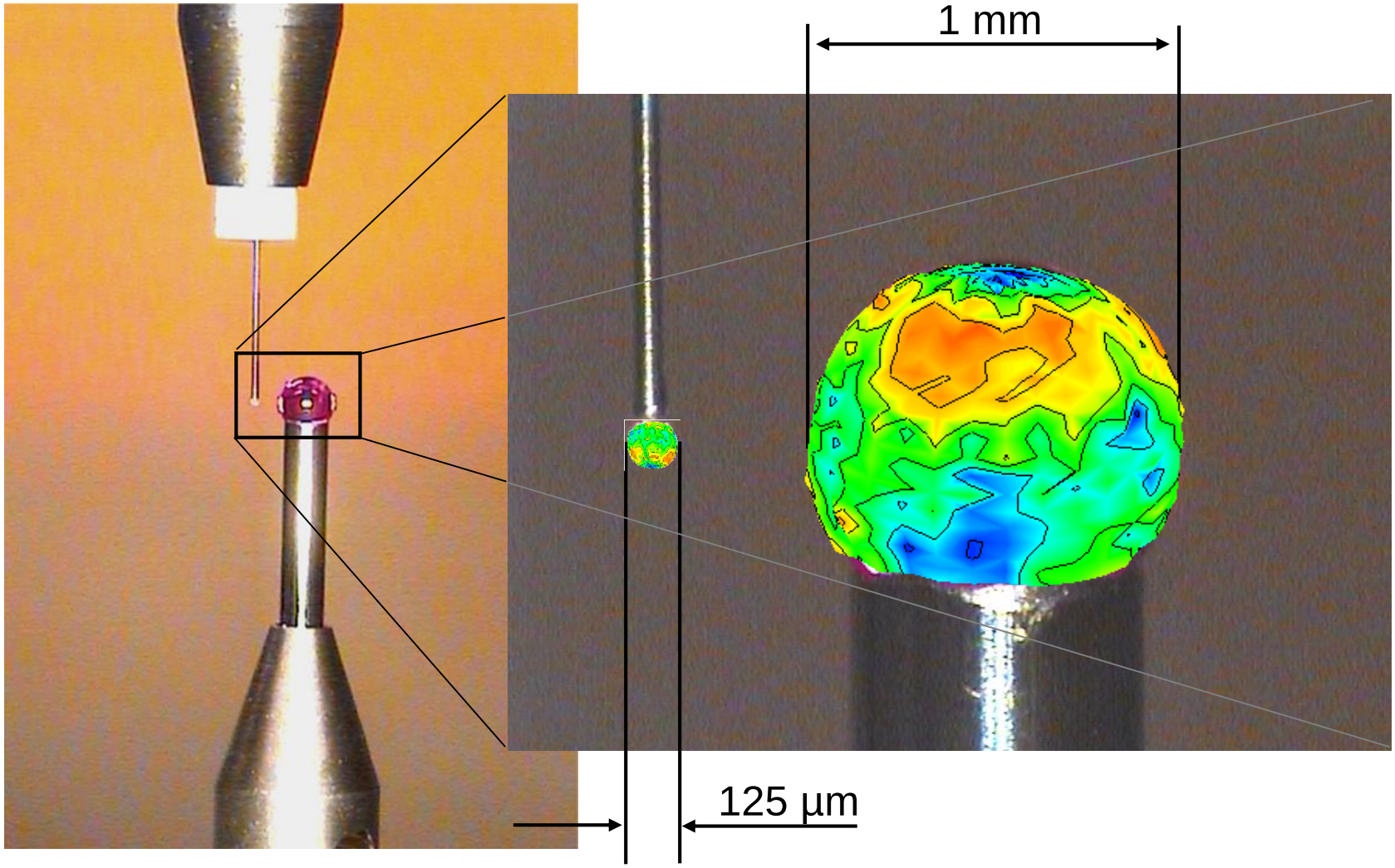




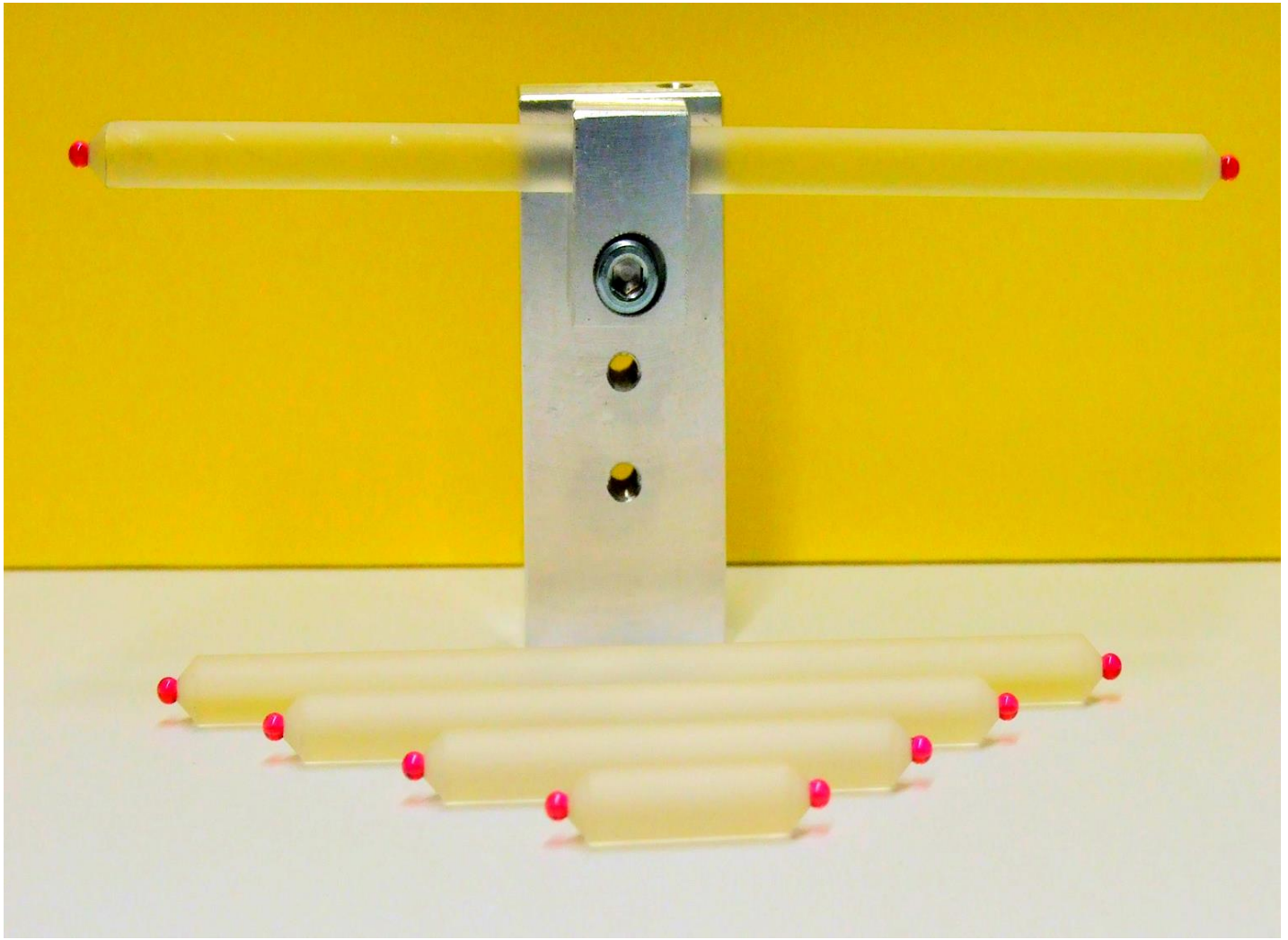
Z- Axis

Flatness = 233 nm

Extended set of probes ranging from 1 mm to 0.125 mm



The µ Ball Bars



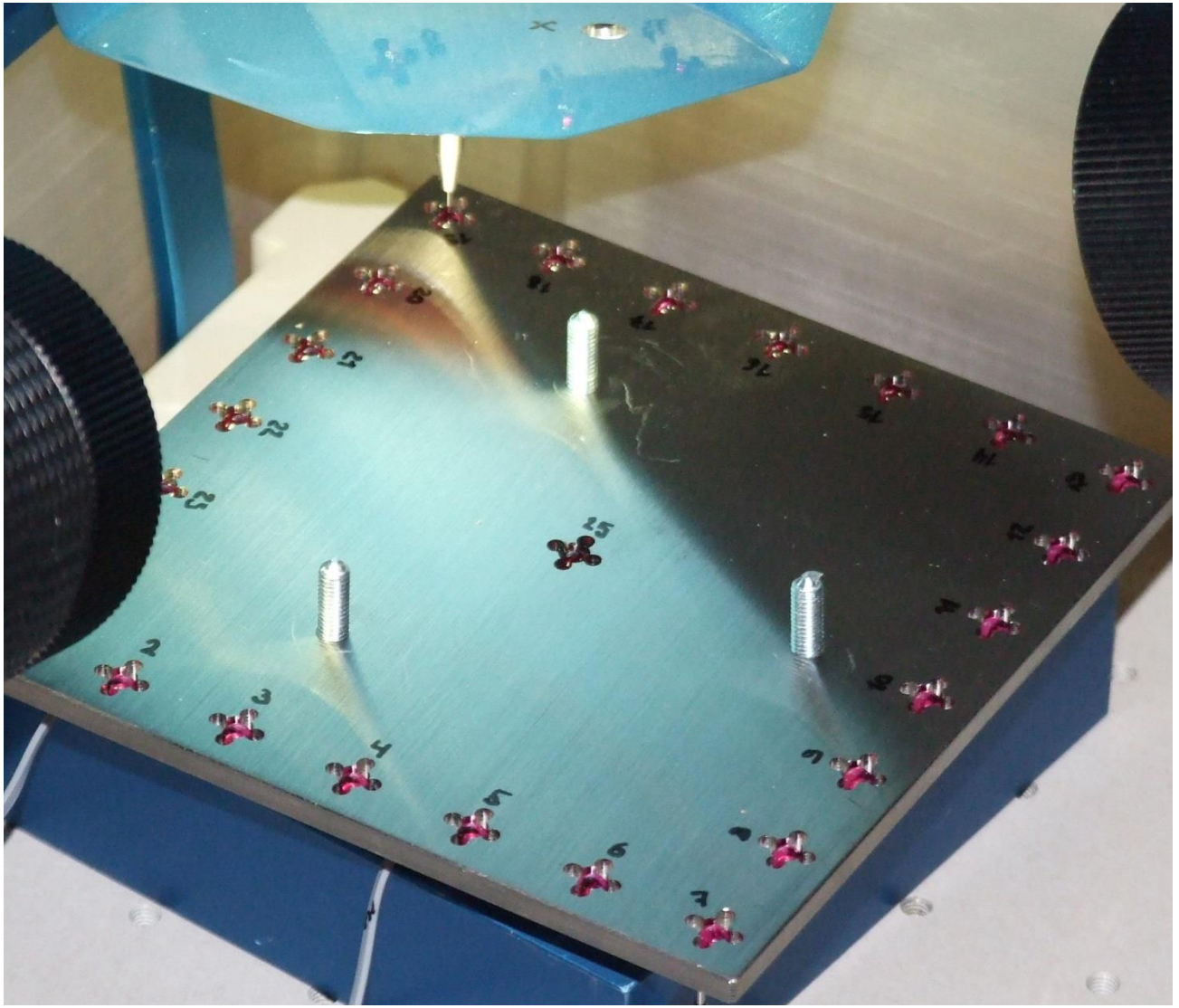
“ISO10360-2” Acceptance test:

7 length along the 4 volume diagonals and the 3 axes

Zerodur bars:
100 mm
80 mm
60 mm
40 mm
20 mm

Sapphire spheres:
Ø = 3 mm

The µ Ball Plate



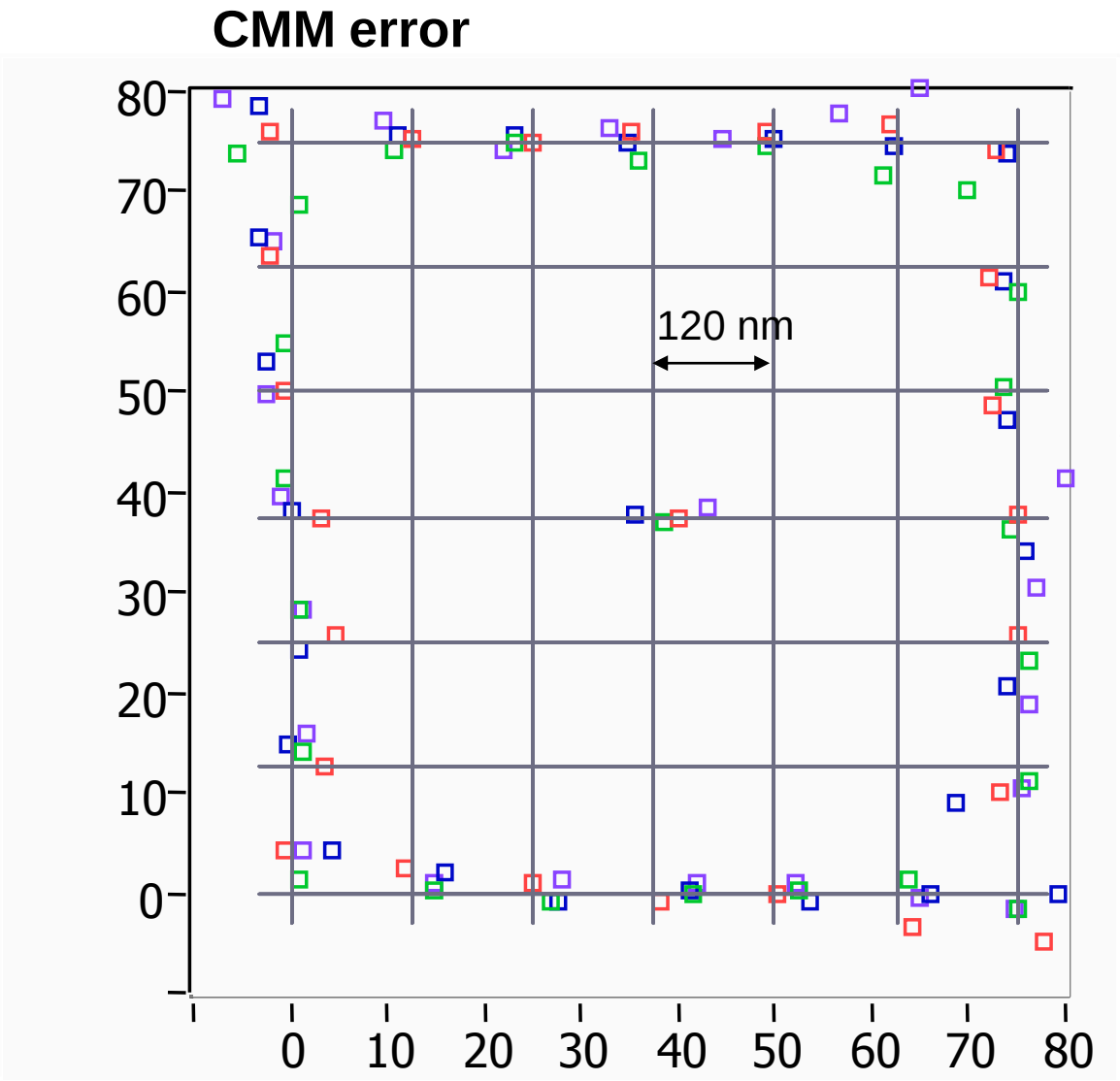
“DKD Richtlinie 2617”

4 measurements with plate flipped along the X then Y axis for error separation

Invar frame:
85 mm x85 mm x 3 mm

25 Sapphire spheres
Ø = 3 mm

µ Ball Plate Results



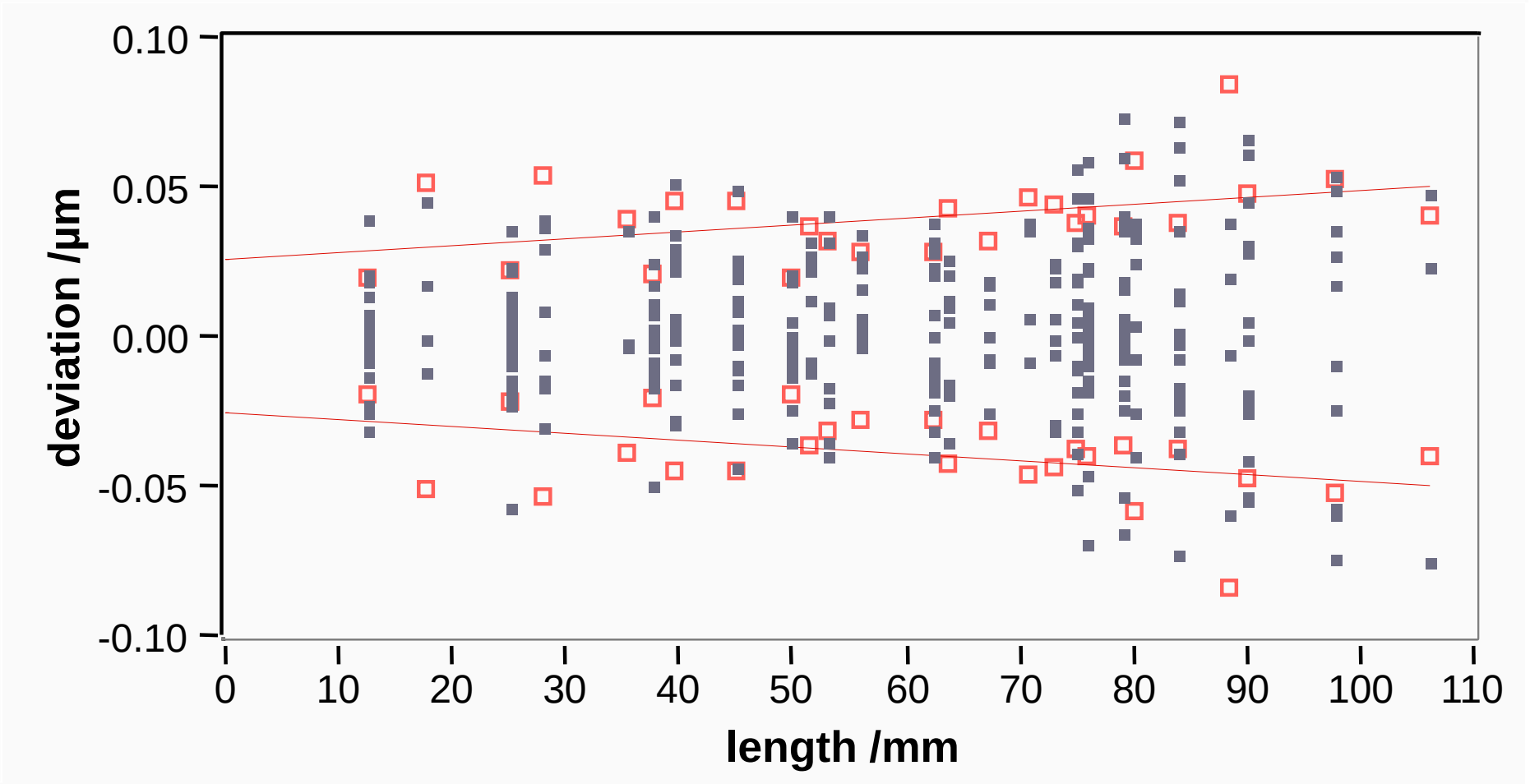
w0
u180
v180
w180

CMM XY angle : 89.999951° (0.17 arcsec error)

Mean repeatability : X: 21 nm Y: 19 nm

µ Ball Plate Results

CMM error



U95 = 26 nm + L/4333 µm/mm

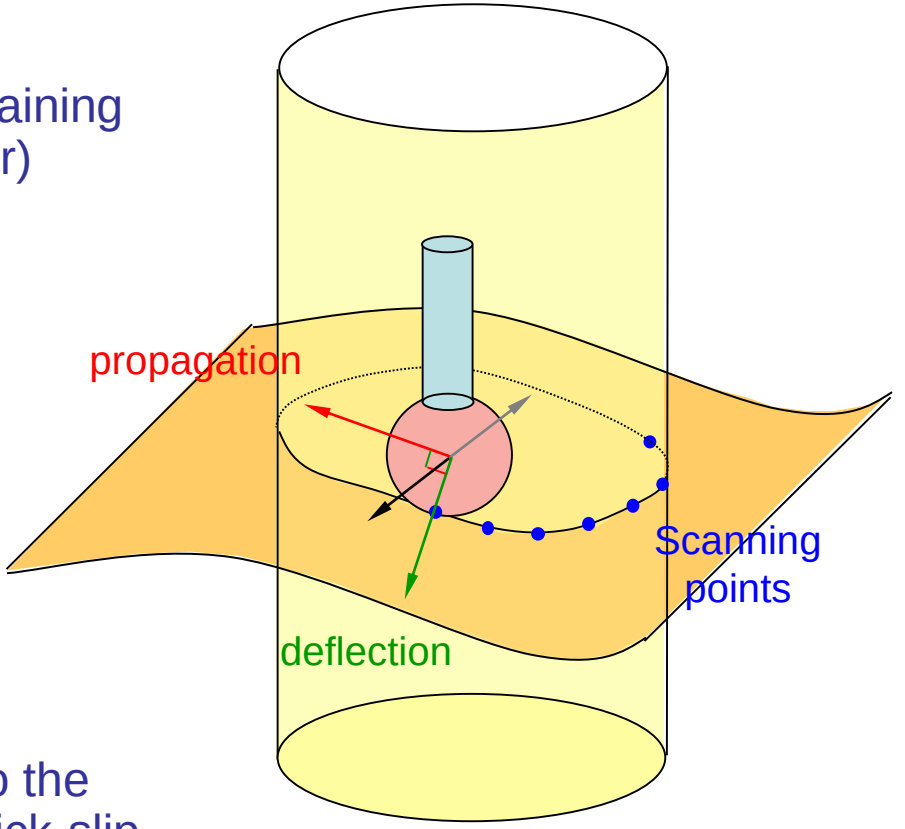
Feedback controlled freeform-scanning

Freeform scanning:
Probing an unknown surface while remaining in a given scan element (here a cylinder)

Possible scan elements are:
Planes, cylinder, axes and cones

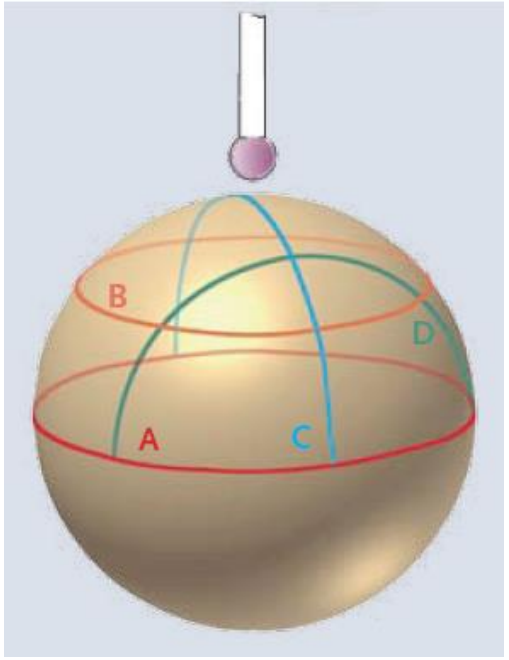
Scanning speeds possible between 0.1 mm/s and 0.6 mm/s

Point density up to 300 p/mm



Feedback control:
Constant probe deflection orthogonal to the surface although there is friction and stick-slip.
Constant scanning speed.
Online determination of the probing direction for correct probe shape correction.

ISO10360-4 scanning acceptance test

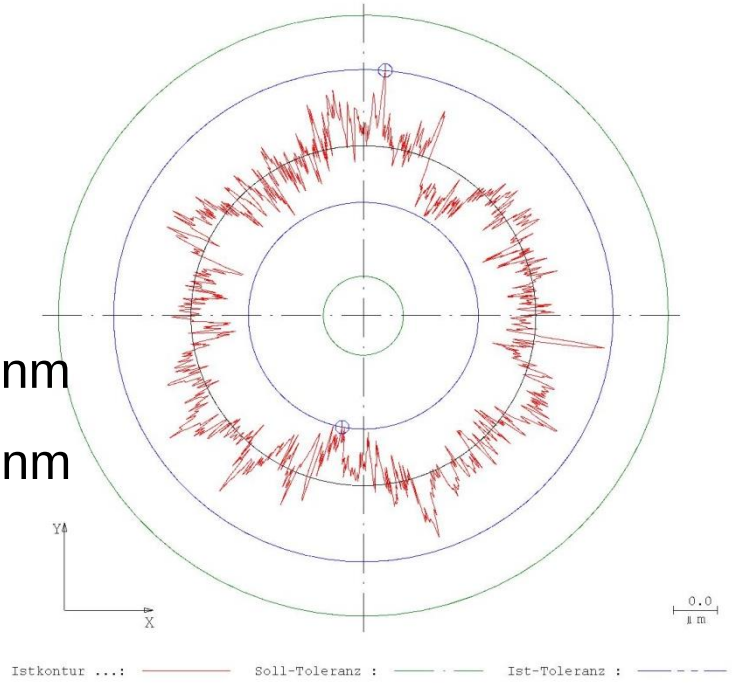


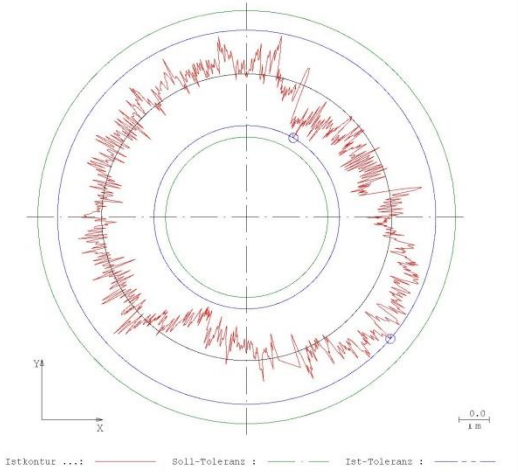
Form Error: 87 nm

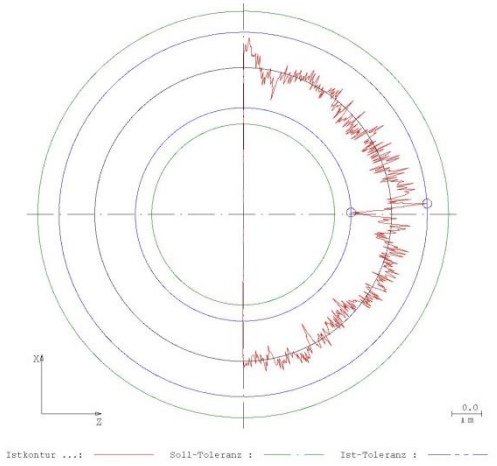
Sphericity: 60 nm

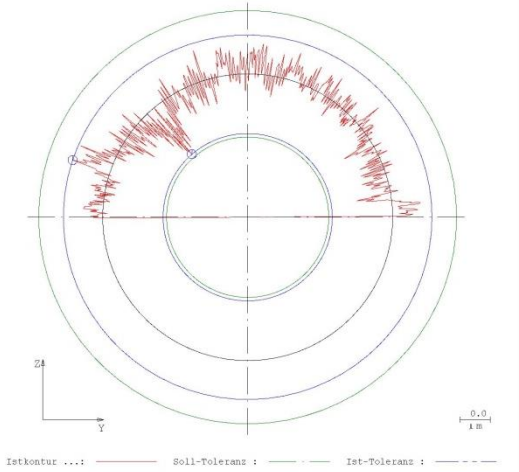
Surf Roughness: 15 nm

Calibration error: 15 nm









Scanning on a 1mm sphere (repeatability)

Experiment:

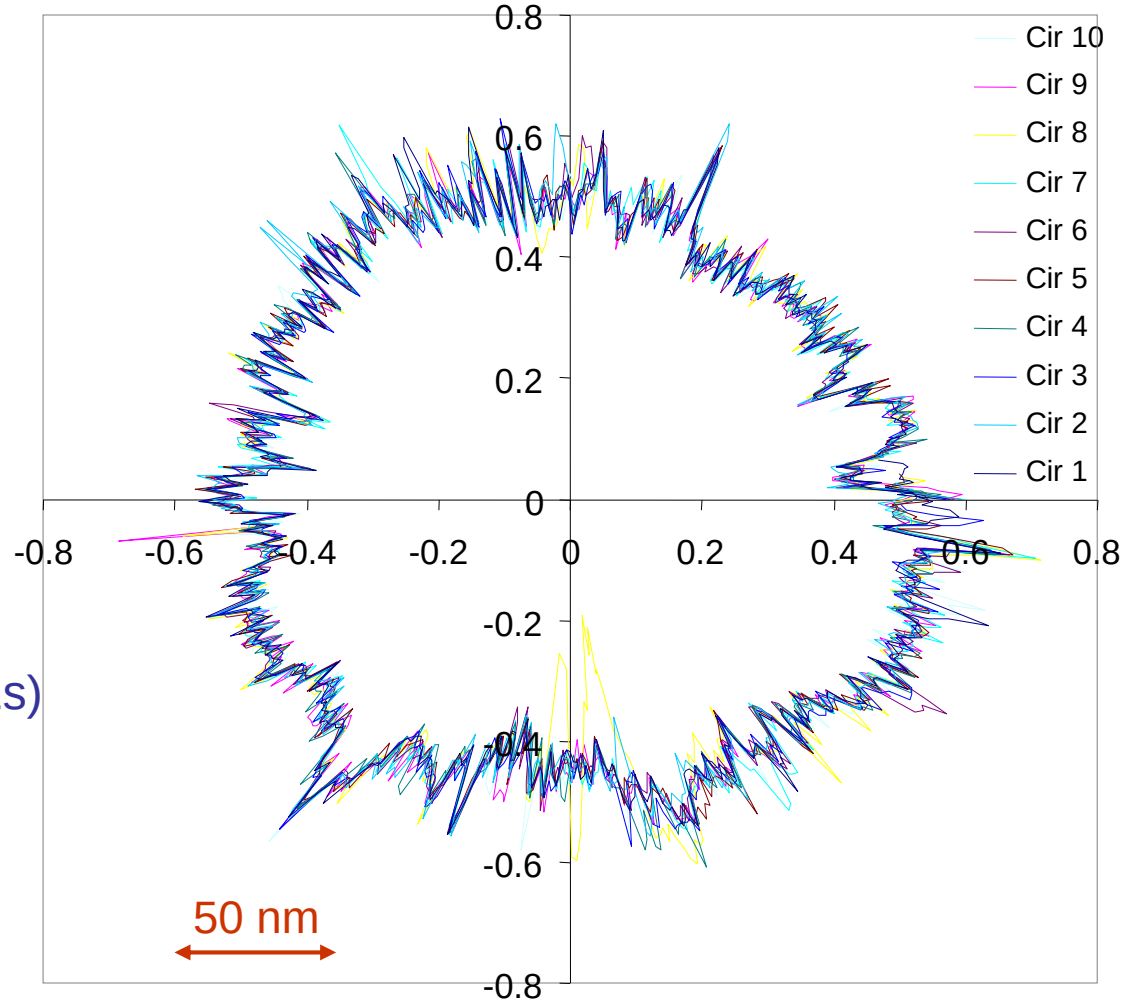
Reference sphere Ø 1 mm scanned at the equator 10 x
Roundness of sphere **34 nm**

Probe: Ø 0.3 mm

Measured roundness: **48 nm** (mean, unfiltered)

Repeatability obtained from 10 measurements: **5 nm** (1s)

High frequency roughness of probe surface: **~10 nm**



Summary

- Identify your needs
- Identify physical limitations
- Think “out of the box” for a solution (disruptive technology)

- Abbe principle
- Metrology loop reduced to its minimum
- Minimize thermal & stress effects
- Simple and compact geometries

- Synchronize the data acquisition
- Apply error separation techniques for calibration
- Use an open software