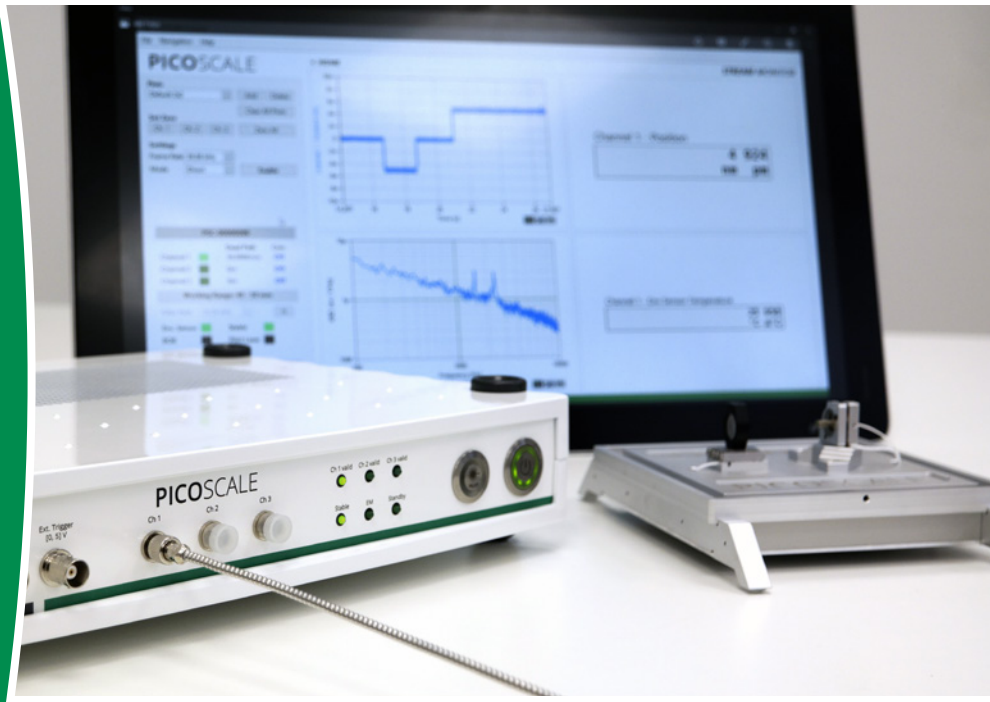
PICOSCALE
Motion and Vibration Measurement



SmarAct

For high precision matters.

Metrology 2020

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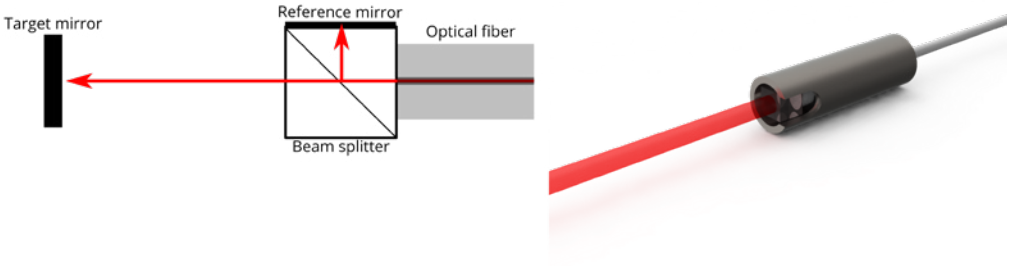
Interferometric Solutions for High Precision Metrology

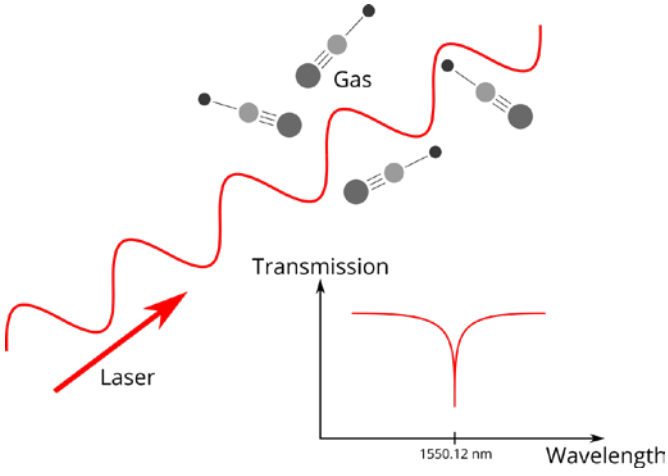
PICOSCALE **Technology**

Picometer Resolution with Laser Interferometry



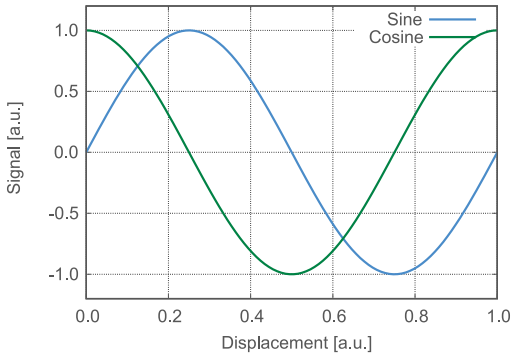
PICOSCALE products are based on laser interferometry for the contactless measurement of displacements and vibrations.
At the beam splitter of an extremely compact Michelson interferometer, the laser beam is divided into two arms. One arm is directed to the target surface while the other is directed to the reference mirror. After the light of both arms is reflected back to the beam splitter, both arms recombine and interference takes place. The interference signal contains information on the displacement of the target surface with respect to the reference mirror.

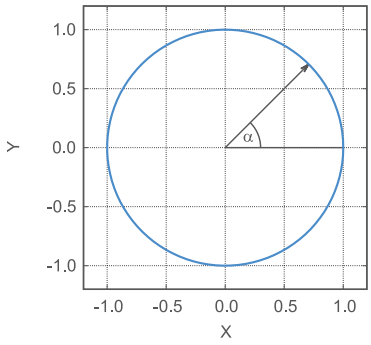
Absolute Accuracy by Laser Wavelength Stabilization



The wavelength of the laser is stabilized to an absorption peak of a standardized gas cell, so that the position data are traceable to standards defined by the National Institute of Standards and Technology (NIST).

Constant High Resolution at Large Displacements with Quadrature Detection





Limitations of conventional interferometry are a very small measurement range with a non-constant sensitivity and the loss of directionality information.
In **PICO**SCALE products this is solved by using quadrature signals. Conceptually, two interference signals are obtained that are phase shifted by 90°. Plotting both signals against each other yields a Lissajous graph. The angle within the Lissajous graph gives the position with picometer resolution, while the direction of motion is directly visible. Larger displacements can be tracked by counting the revolutions.

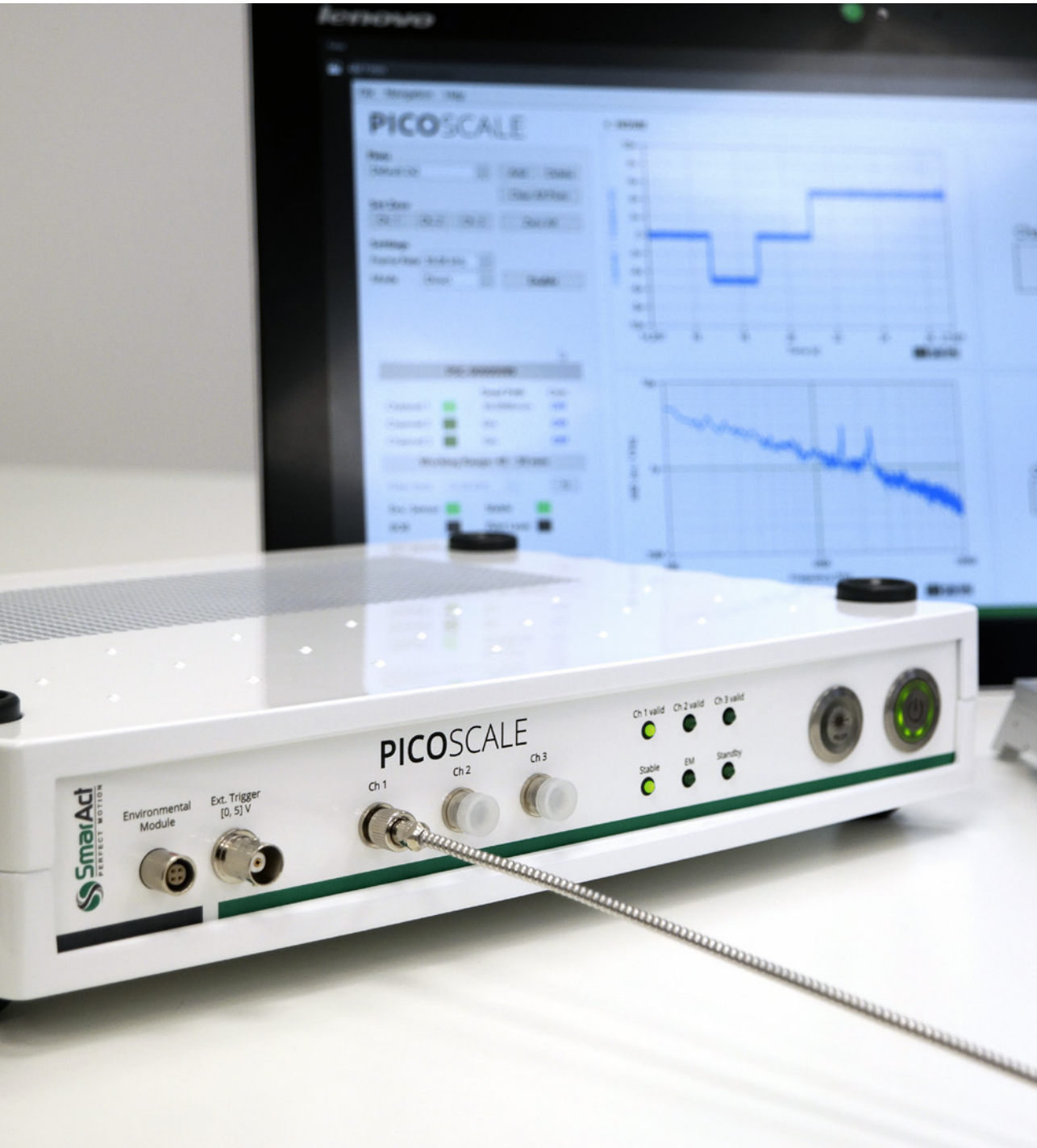
Real Time Data Processing with Advanced Firmware Modules

The measured interference signals are processed in the **PICO**SCALE field programmable gate array (FPGA) in order to obtain displacement data with stream rates up to 10 MHz. The FPGA can be configured to perform for example real-time angle calculations or lock-in detection.

*At Sirius Light Source, in the Brazilian Synchrotron Light Laboratory (LNLS) and the Brazilian Center for Research in Energy and Materials (CNPEM), SmarAct **PICO**SCALE Interferometer has been used by designers and engineers in several beamline applications over the last five years. The first case was the High-Dynamic Double Crystal Monochromator (HD-DCM), in which the **PICO**SCALE Interferometer is used as an embedded feedback sensor in a high-bandwidth closed-loop control system, allowing for the breakthrough crystal-to-crystals angular stability of 10 nrad RMS (integrated up to 2.5 kHz) both in fixed-energy and flyscan operation modes. The main reason for the choice was the combination of high resolution and high feedback rates with convenient volume claims for the heads and for the optical fibers. Yet, the complete software interface, allowing us to debug and optimize operation, was essential to achieve the final performance. Moreover, the SmarAct development and support teams were always promptly available to help, from simple questions to specific development needs. From this successful collaboration, **PICO**SCALE has now been chosen for many other applications in our new 4th-generation synchrotron facility, particularly as metrology items in the most recent microprobe and nanoprobe end-stations.*

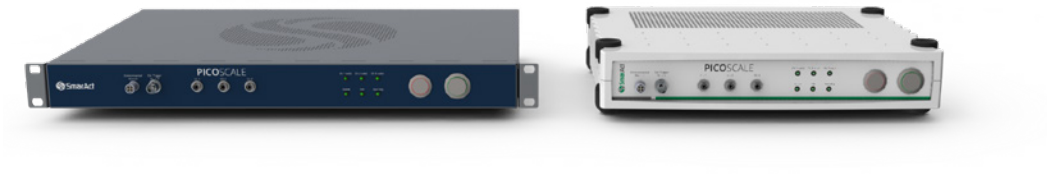
+++ Ricardo Caliari and Renan Ramalho Geraldes
+++ Brazilian Synchrotron Light Laboratory (LNLS), Campina, São Paolo, Brazil

Displacement Measurements



High Precision Displacement Measurements with the PICOSCALE *Interferometer*

- 3 parallel laser interferometers in one instrument for 3D measurements
- Measurement bandwidth up to 2.5 MHz (10 MHz data rate) with a resolution down to 1 pm
- Measurements possible on most materials (mirrors, retro-reflectors, plastic, glass, metal and even water)
- Wide range of sensor heads available for different applications and environments (including vacuum and cryogenics)
- Proven performance with many satisfied customers



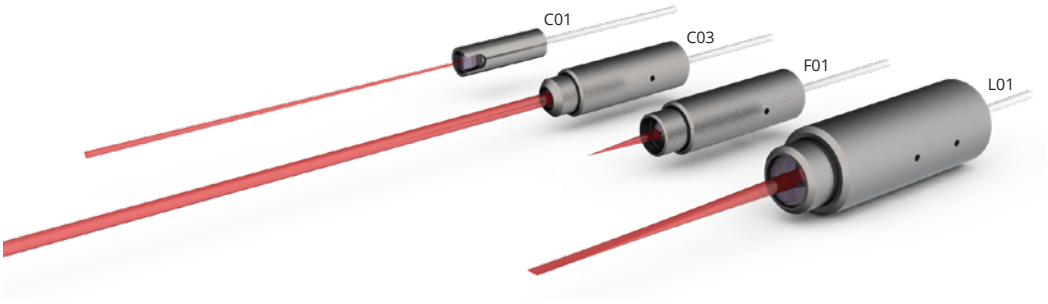
***PICO**SCALE Interferometer controllers are available in two different housings.*
Left: Rack mount housing, 48.2 x 31 x 4.5 cm
Right: Table-top housing, 33 x 27 x 7.2 cm

Interferometer Controller

- Laser source and detection electronics
- Realtime data processing in FPGA
- Versatile digital and analog interfaces

Key Specifications	
Channels	3
Resolution [pm]	1
Maximum Target Velocity [m/s]	2
Maximum Working Distance [m]	1
Data Rate [MHz][1]	10
Noise[2]	1 pm / √Hz @ 1 kHz 70 pm RMS (band 100 Hz ... 1 kHz)
Target Reflectivity[3] [%]	4 - 100
Laser Wavelength[4] [nm]	1550 Laser class 1 (eye-safe) Visible pilot laser to assist initial alignment
Environmental Compatibility	Ambient, ultra-high vacuum, cryogenics
Controller Chassis	33 x 27 x 7.2 cm, weight 3.5 kg (tabletop) 48.2 x 31 x 4.5 cm, weight 3.8 kg (19" rack)

[1] Maximum bandwidth of position data is 2.5 MHz
[2] Working distance 20 mm, ambient conditions
[3] Not crucial because of Michelson interferometer principle
[4] Stabilized with gas absorption cell, NIST traceable



Interferometer Sensor Heads

- C01: Compact sensor head for general purpose
- C03: Collimated measurement beam for large working distance
- F01: Focused beam with high angular working range for small samples
- L01: Line-focused beam for runout measurements of cylindrical targets

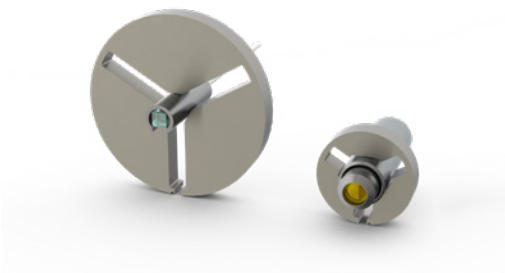
	C01	C03	F01[1]	L01
Beam Geometry	Collimated		Focused	Line-focussed
Focal Distance [mm]	-		10	30
Beam Waist Diameter [µm]	400	1590	28	50 x 1590
Working Distance [mm]	13 ... 650	0 ... 1000	10 ± 0.5	30 ± 10
Angular Working Range [°]	± 0.05	± 0.013	± 2	± 1.3 (along focused axis)
Environmental Compatibility	Air, HV, UHV, CRYO	Air, HV, UHV		
Typical Targets	Mirror	Retro-Reflector	Small Samples	Cylindrical Samples
Dimensions [mm]	4 x 13	6 x 21	6 x 21	9 x 26

[1] Values are for a focal distance of 10 mm.
Other focal lengths on request.

*We are using a **PICO**SCALE line focusing sensor head to track the motion of a polished cylinder in our synchrotron beamline. This allows us to close a feedback loop and rotate the cylinder without eccentricity or – thanks to the large tolerances of the sensor heads – with a stub offset.*
+++ National Synchrotron Radiation Research Center (NSRRC), Hsinchu, Taiwan

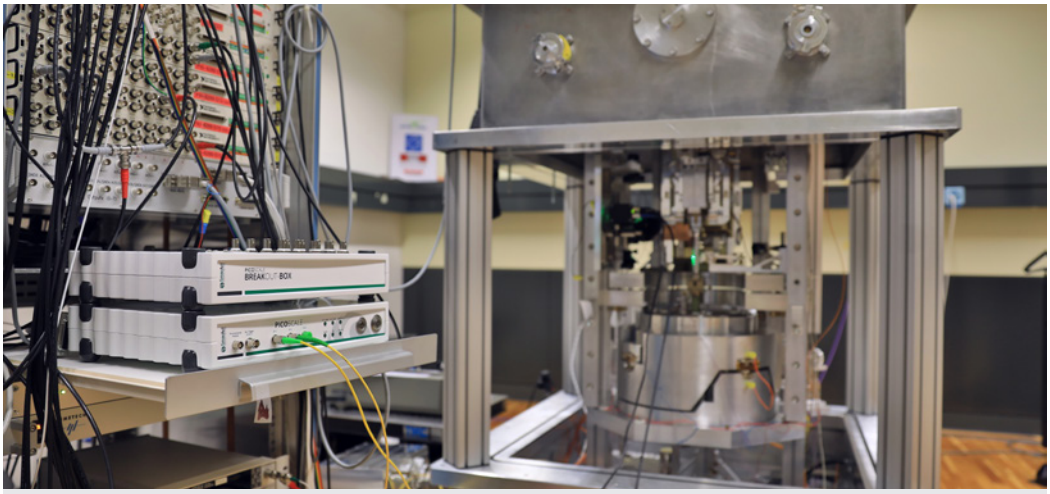
***PICO**SCALE Controller with accessory components: Breakout Box for convenient access to digital and analog signals, Temperature Box to read up to ten PT1000 temperature sensors, Environmental Module for compensation of air temperature, pressure and relative humidity.*

Key Specifications		
PICOSCALE Controller	USB und Ethernet	Data transfer to a user PC with up to 10 MHz data rate.
	Trigger Input	1 Trigger input at front panel
	SmarAct SI Interface	Direct link to SmarAct's motion controllers, e.g. MCS2
PICOSCALE Breakout Box	Serial Data	Serial data transmission of displacement or Calculation System data
	AQuadB	Incremental transmission of displacement or Calculation System data
	Analog Input	3 analog-to-digital converters with 16 bit resolution
	Analog Output	5 digital-to-analog converters with up to 16 bit resolution
	Trigger Input/ Output	9 digital inputs/outputs for synchronization with external devices
Additional Sensors	Environmental Module	Sensors for air pressure, temperature and relative humidity for compensation of changes in the refractive index of air
	Temperature Box	10 channels for resistive temperature sensors (PT1000)



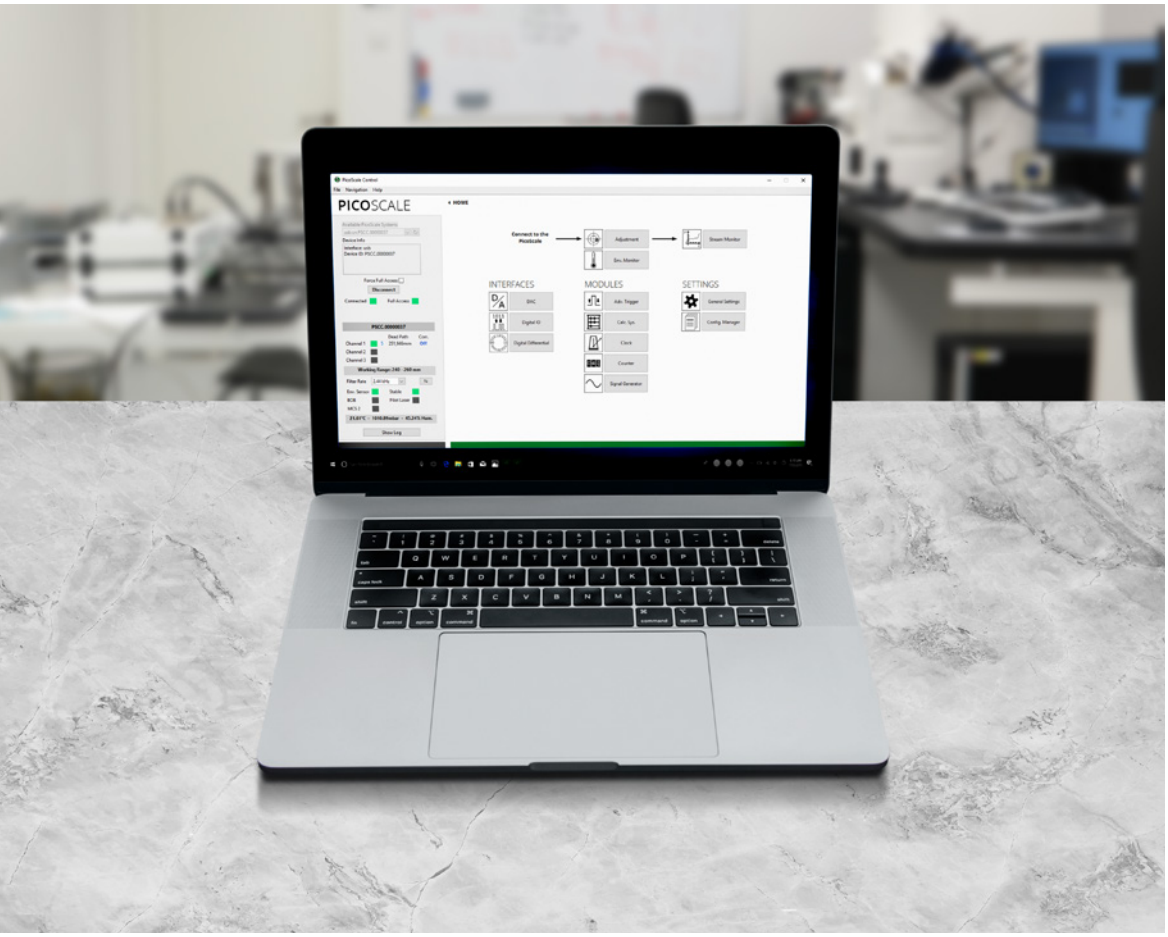
Sensor Heads can be installed in standard optomechanical holders with convenient mounting accessories.

***PICO**SCALE Sensor Heads can be equipped with different tubings for enhanced robustness or specific environments.*



*The watt balance is comparing mechanical and electrical powers. In a first step, the mechanical force on a test mass in the earth's gravitational field is balanced with an electro-magnetic force using a current-carrying coil. In a second step, the coil is moved through the magnetic field, which induces a voltage. The precise knowledge of the electrical, gravitational and dynamical properties allows to infer the mass in terms of natural constants only - instead of using the prototype mass in Paris. One requirement during the two phases of the experiment is the accurate determination of the position and angular orientation of the coil. This measurement is performed using the **PICO**SCALE Interferometer.*

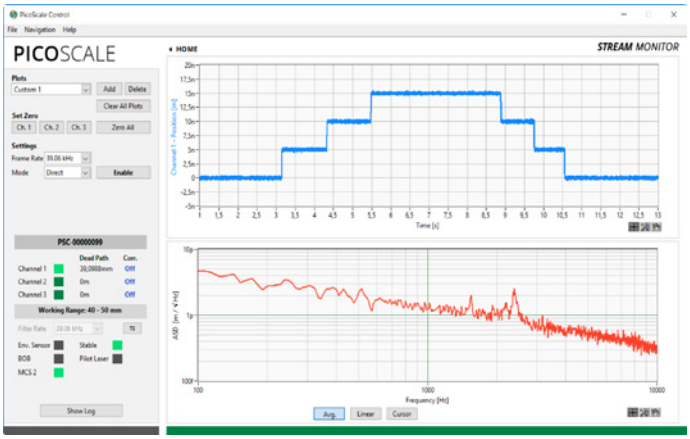
+++ Dr. Henri Baumann
+++ METAS, Federal Institute of Metrology, Berne, Switzerland



Key Features

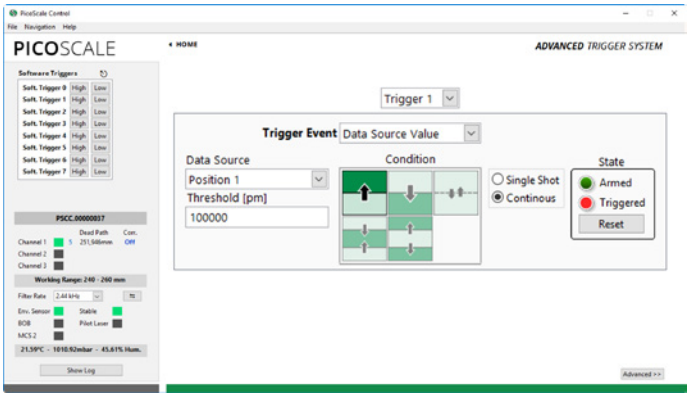
- Multi-user ready: simultaneous interaction by a master user and an observer
- Software API with all drivers, libraries and programming examples for customized control software
  - LabVIEW
  - C/C++
  - Python
- All functions are combined in the convenient graphical user interface "**PICO**SCALE Control"

*We are using the **PICO**SCALE as a position encoder for our motors and we will integrate the device in our HF facilities soon. We are very happy with the LabVIEW drivers that came with the system that allow us to combine our motion controllers with high precision displacement sensors in a single software tool.*
+++ S. Martens
+++ University of Hamburg, Germany



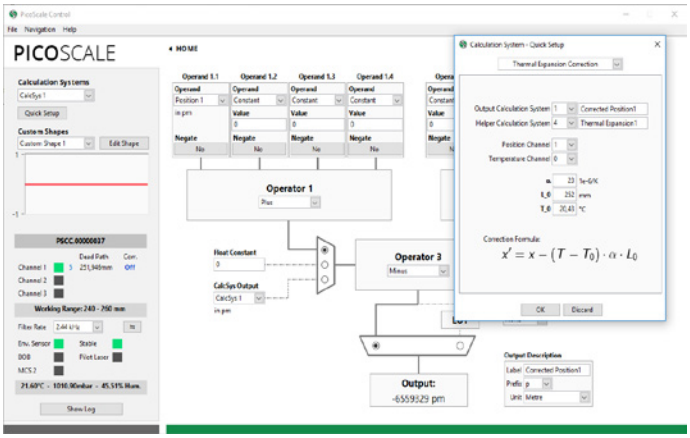
Stream Monitor

- User-friendly options to display and export data
- Spectral analysis using FFT functions
- Streaming data to a file
- Triggered streaming



Advanced Trigger System

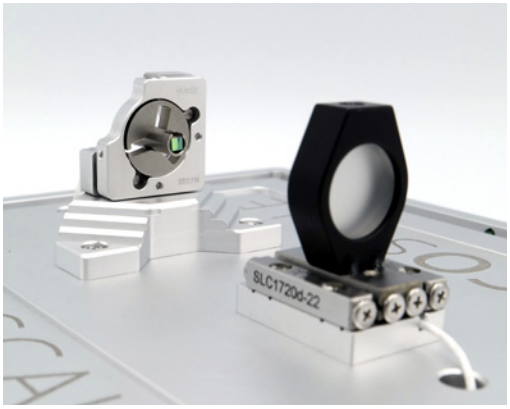
- Configuration of triggers for device synchronization
- Alerts in case of signal loss
- Event counter
- Clock input/output



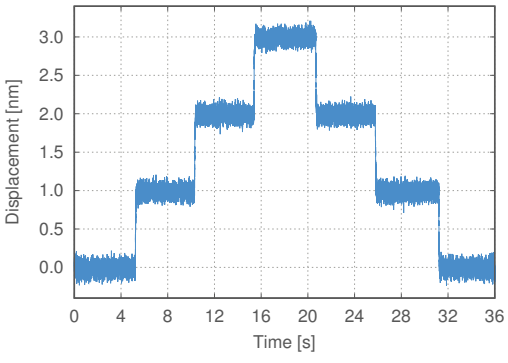
Calculation System

- Calculation of angles
- Thermal compensation
- Mapping of data with look-up tables
- Other user defined calculations

Closed-Loop Positioning

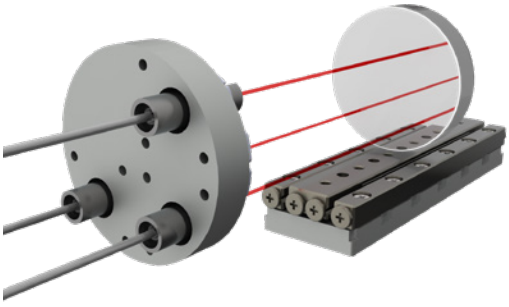


- Displacement encoding with measurement directly at the point of interest
- Low-latency feedback control with direct link between **PICO**SCALE and **MCS**2 motion controller

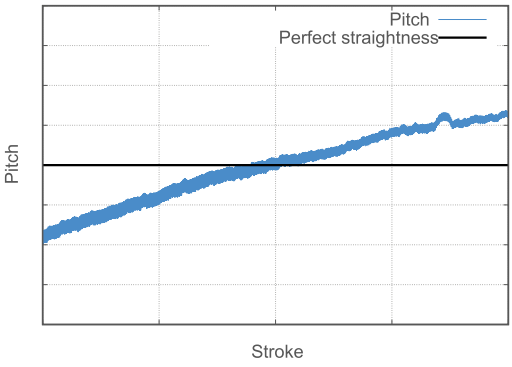


*Closed-loop positioning in 1 nm steps using the **PICO**SCALE Interferometer with a direct link to SmarAct's motion controller **MCS**2.*

Quality Control of Translation Stages



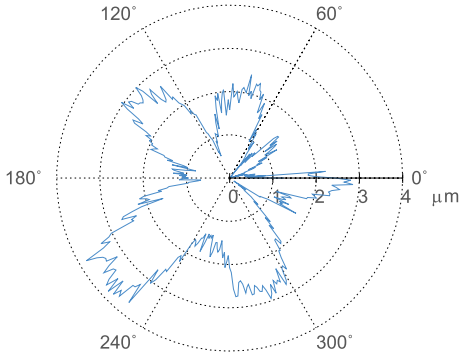
- Simultaneous measurement with 3 channels
- Compact and light sensor heads and targets
- Fast angle calculation in the system's FPGA
- Analysis of translation stages in 3D (z, Rx/yaw, Ry/pitch)
- Typical example of our measurement service, see page 22



Exemplary pitch measurement of a translation stage over its entire travel range.

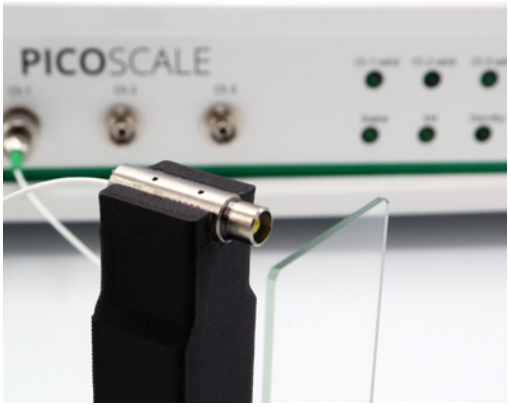
Radial Runout Measurement of a Rotating Cylinder

- Line focusing sensor heads aligned with rotating cylinder
- Measurements of radial runout and wobble
- Large tolerance to stub-offsets
- Sample positioning in synchrotron beamlines

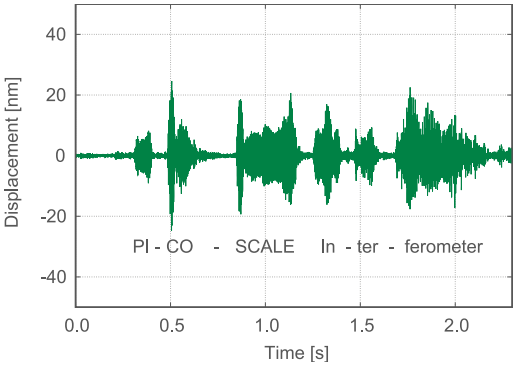


Radial runout of a rotating cylinder. This information can be used to control the center of rotation.

Measurement on a Glass Window

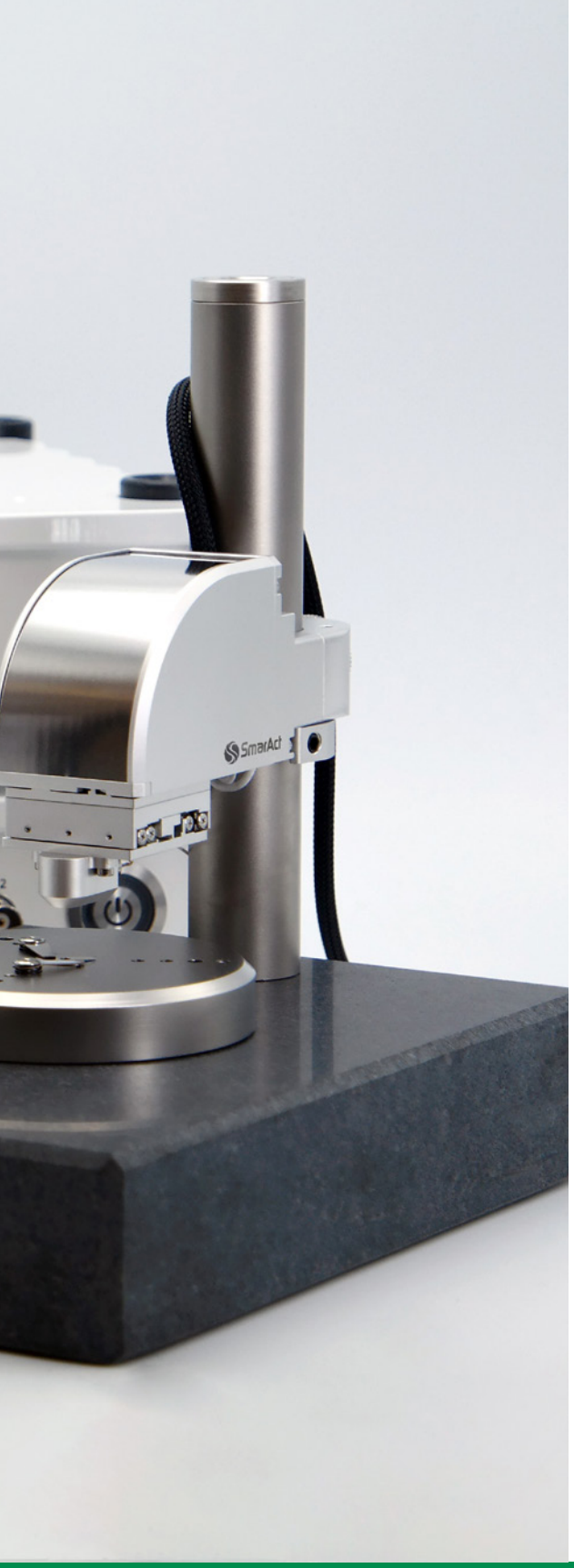


- Focusing sensor head directed at a glass window
- Direct streaming of position data into a file for subsequent data processing



*Sound waves of a human voice excited the glass window and the displacement is measured with the **PICO**SCALE Interferometer.*

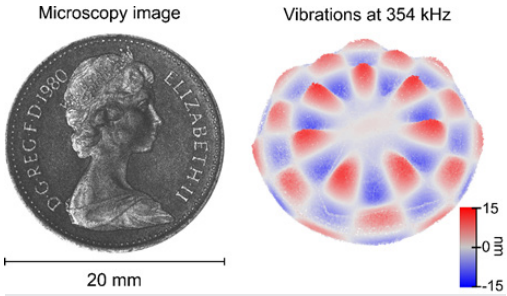

SmarAct
Environmental Module
Laser
PICOSCALE Vibrometer
Standby
Stable
EM
SmarAct
Scanning Stage
Sensor
Shaker
PICOSCALE Stage Controller
Standby
Status
Shaker
GPIO 1



Megapixel Modal Analysis of Small Samples with SmarAct's Scanning Vibrometer

Vibration measurements at up to one megapixel can be performed with SmarAct's scanning vibrometer, the solution for the modal analysis at high spatial and temporal resolution for samples such as MEMS, sensors and actuators.

- Contactless measurement of vibrations with a resolution of under 1 pm
- Up to 10 MHz sample rate to investigate vibrations up to 2.5 MHz
- Confocal optical design with an IR measurement laser
- Measurements possible through semi-transparent enclosures of plastic, glass and silicon
- Integrated confocal microscope with an optical resolution down to 2 µm
- Microscopy images are intrinsically aligned with vibration measurements
- Turn-key instrument complete with shaker stage and software



*Higher order bending modes can result in complex vibrational patterns. For a full modal analysis, the measurement laser of the **PICO**SCALE Vibrometer is scanned over the sample to record microscopy and vibration images simultaneously.*

Scanning Vibrometry
System Components

1 Innovative Sensor Head

- Integrated Michelson interferometer
- Confocal optical design
- Various microscope objectives available

2 Closed-Loop 3D Positioning System

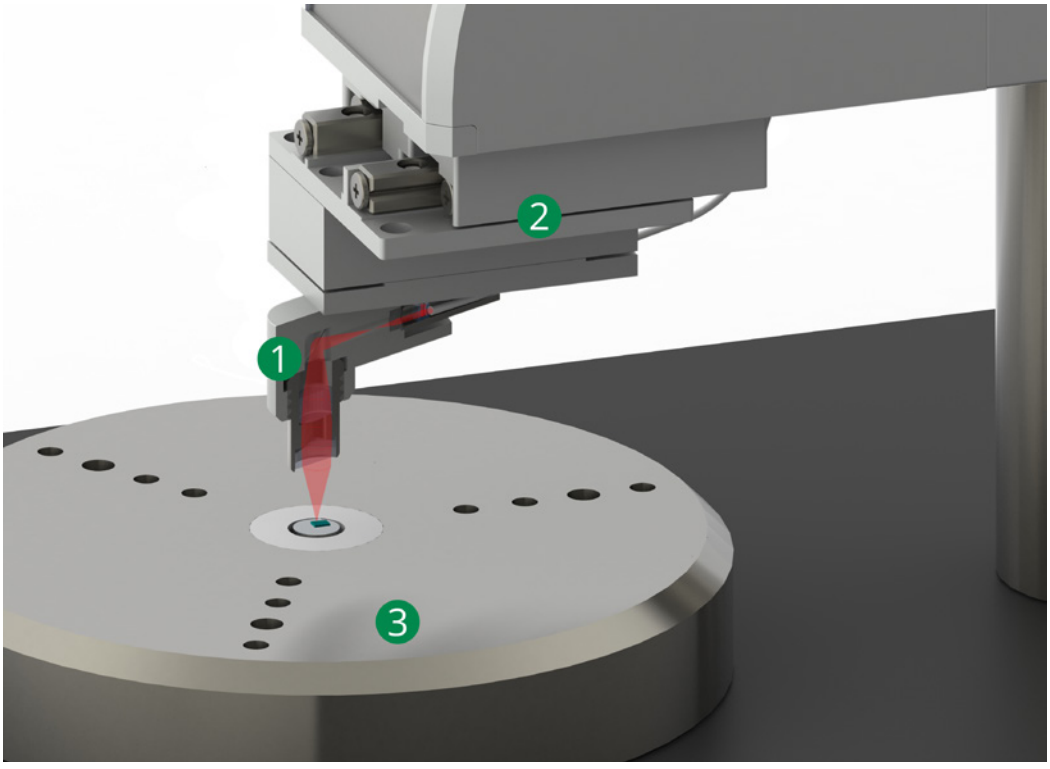
- Closed-loop piezo positioners with nm resolution
- Scan range of 20 mm
- Highly reproducible positioning of laser beam
- Easy integration in custom setups through 1” post mount
- UHV compatible upon request

3 Shaker Stage

- Mechanical excitation of samples by a fast piezo-based shaker stage
- High bandwidth of more than 1.5 MHz

Controller

- Class 1 laser coupled to the sensor head with fiber optics
- Configurable lock-in amplifier for the direct imaging of bending modes
- Vibration data can be processed in the time or frequency domain
- Outputs available for the electrical excitation of samples
- Synchronization with external function generators through trigger output



Software

The **PICO**SCALE *Vibrometer* is delivered with two programs that can be operated in parallel:

- Intuitive operation of the vibrometer with the Control software
- Extensive data analysis with the View software

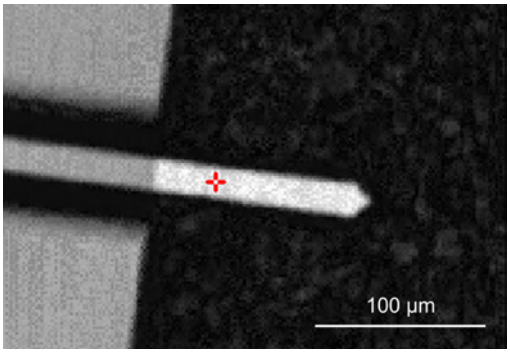
Key Specifications		
Vibrometry	Resolution[1] [pm]	< 1
	Bandwidth[2] [MHz]	2.5
Microscopy	Optical Lateral Resolution[3] [µm]	2 - 7
	Optical Axial Resolution[3] [µm]	7 - 90
	Working Distance[3] [mm]	1.5 - 10
	Maximum Image Size [mm]	20 x 20
	Minimum Pixel Size [µm]	1
	Maximum Number of Pixels	1000 x 1000
Dimensions	Controller	2 units of each 33 x 27 x 7.2 cm (W x L x H), combined weight 7.6 kg
	Scanning Stage	5.5 x 11.0 x 7.5 cm (W x L x H), weight 0.25 kg
	Instrument Mount	Granite stone 15 x 20 x 4 cm (W x L x H) with stainless steel post 2.5 x 15 cm (Ø x H), combined weight 4.3 kg
	Shaker Stage	8 x 1.5 cm (Ø x H), weight 0.5 kg

[1] When analyzing displacements in the frequency domain

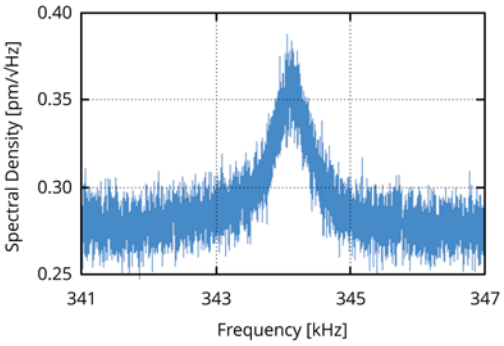
[2] Sampling rate is 10 MHz
[3] Depending on the selected sensor head

*The **PICO**SCALE Interferometer is used in an experiment to precisely measure the oscillation amplitude of a mechanical oscillator. We operate the system at temperatures from -50 to 0 degree Celsius and study friction of samples. The sub-Angstrom noise level of the interferometer and its convenient output in combination with a third party Phase-Locked Loop eventually enabled the acquisition of very precise AFM images.*
+++ A. Niguès
+++ Laboratoire de Physique de l'École Normale Supérieure (UMR CNRS 8550), Paris, France

Single Point Measurements

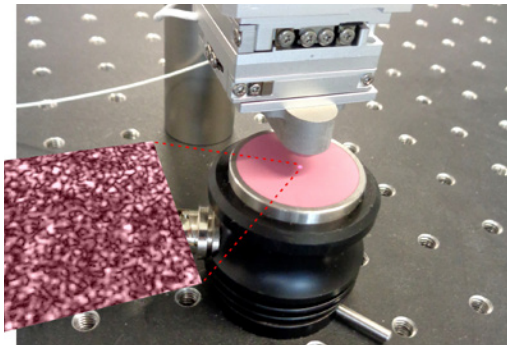


- Measuring out-of-plane vibrations with interferometry
- Easy selection of measurement points with integrated optical microscope
- High resolution and bandwidth

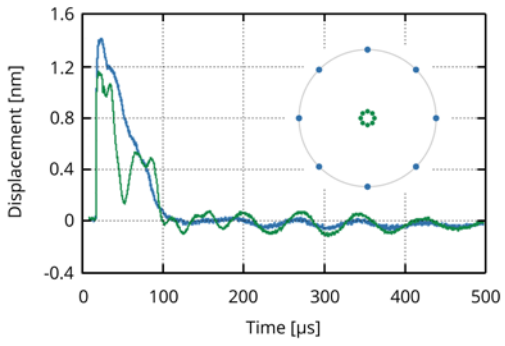


The amplitude spectrum of a micro cantilever was measured at the indicated position. Although the cantilever was not actively excited, the high resolution of the interferometric measurements still allows to detect the thermal fluctuations, in this case 0.36 pm at 344 kHz.

Characterizing Ultrasonic Transducers

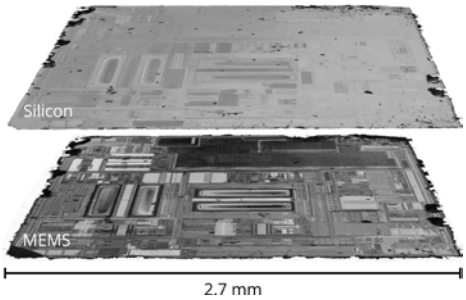


- Measuring sub-nm motion at multiple predefined points
- Sample excitation with external arbitrary waveform generator

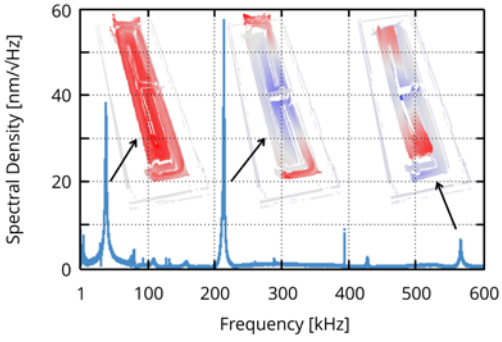


Measuring motion at a circular array of points on the surface of an ultrasonic transducer. The graphs show the averaged response from all measurements performed at 1.3 mm (green) and 10 mm (blue) from the transducer center. We thank Vallen Systeme GmbH for their support with this application example.

Measuring MEMS through Silicon

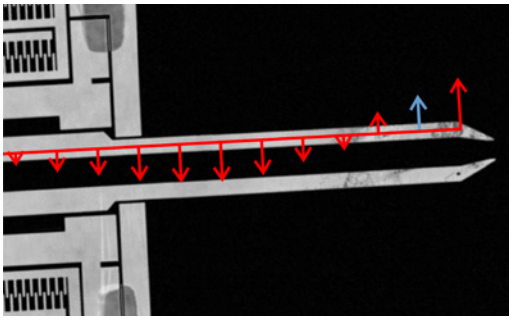


- Selective imaging of layers with infrared confocal microscopy
- Measuring through semi-transparent materials such as glass and silicon
- Semi-transparent structures themselves can still be measured when in focus

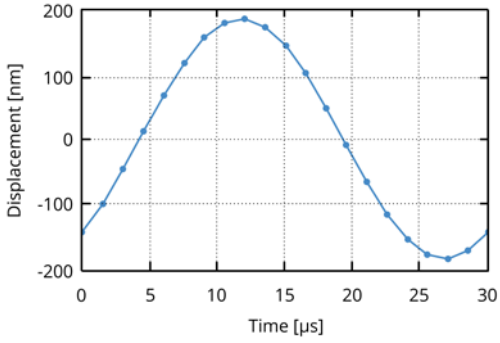


Measuring vibrations of MEMS through a packaging of silicon is made possible by confocal imaging with an IR light source. We thank InvenSense, a TDK Group Company, for their support with this application example.

Imaging Lateral Vibrations



- In-plane motion is imaged by recording a sequence of microscopy images that span exactly one vibration cycle (conceptually similar to stroboscopic imaging)
- In plane vibrations down to 10 nm can be extracted through optical flow algorithms



Lateral vibrations are measured by recording a sequence of microscopy images. Of any moving part within the images the motion can be quantified with a tracking routine. Although this method is based on microscopy, and not on interferometry, the resolution is not limited by optical diffraction and can be as good as a few nm.

Measurement and Rental Services

Measurement Services

- Simplify your development process by outsourcing specific measurement tasks
- Results are reported according to established or customer defined standards.
- Benefit from our long-standing expertise in displacement and vibration measurements
- Get faster approval for measurement services as opposed to an investment in technology

Rental Services

- **PICO**SCALE Interferometers and Vibrometers can be rented on a weekly or monthly basis
- Direct support from SmarAct's application engineers
- Benefit from the latest equipment
- Evaluate the impact of new measurement capabilities prior to an investment decision

Take the next step

Our measurement and rental services can help to optimize your development process but also to solve a one-off problem that limits the performance of your product. Please contact us to discuss your requirements and plan a pilot study today.

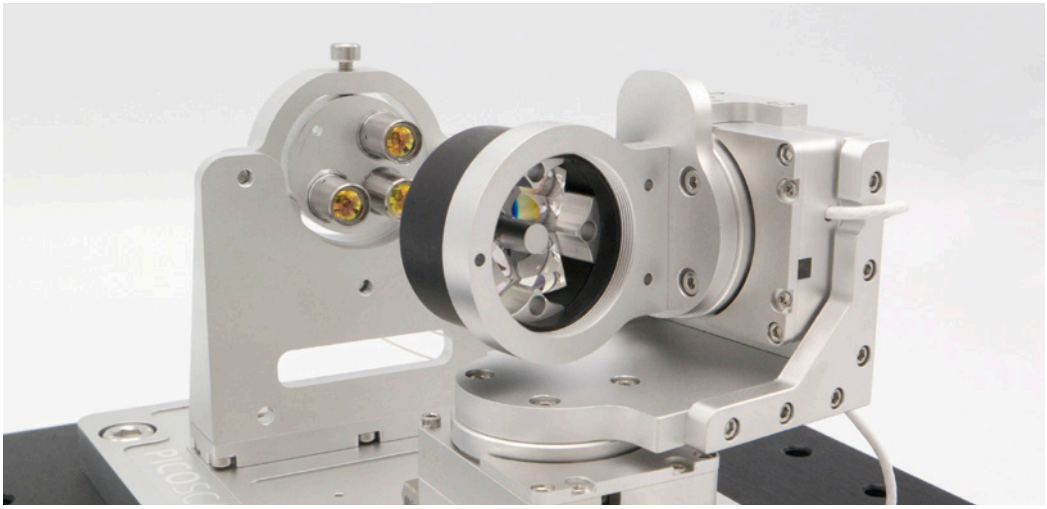
Typical Customer Applications

Characterizing vibrational modes with laser scanning vibrometry.

- MEMS
- Wire bonds
- Voice coil motors
- Ultrasonic transducers
- Micro-loudspeakers
- Hearing aids
- Acoustofluidic devices
- Noise source identification for microscopy (AFM, EM)

Multi-dimensional analysis of motion at unsurpassed resolution by parallel interferometric displacement measurements.

- Calibration and validation of positioning and motion systems
- Repeatability and accuracy
- Thermal stability
- Tip/tilt of target during translation
- Radial run-out of a rotating system



Customize SmarAct's PICOSCALE products to meet your specific demands

- Different lengths of cables and optical fibers
- Special sensor head options
- Special data acquisition and evaluation software
- Combination with SmarAct's positioning systems

Let us integrate our metrology solutions into your system

- Engineering services and consultancy
- Special sensor head development and mounting options
- Adaption of data interfaces and protocols
- Vacuum, cryogenic or radiation compatibility

Take the next step

Our customization and integration services allow you to tailor fit **PICO**SCALE products to your exact requirements, from a one-of-a-kind solution to OEM. We offer multiple levels of support ranging from a simple modification to a full integration in an existing system. Please contact us to discuss your requirements.

Typical Customer Applications

Closed-loop position control

- Wafer positioning
- Lithography
- Coordinate measurement machines
- Milling machines

In-line process and Quality Control

- Tolerance analysis
- Dynamic performance of actuators

*Multimodal studies on nanoscale specimen are of crucial interest for research fields such as scanning electron microscopy (SEM). In a novel experiment, the **PICO**SCALE Interferometer was used to collect information on the topography of a sample by sensing the dynamics of an atomic force microscopy cantilever. Simultaneously, the probe could be analyzed with SEM resolution and thus, two microscopy methods are fused. SmarAct offered customized solutions to integrate the compact sensor heads into the setup and enabled creating a microwave microscope inside an SEM as a world-first.*
+++ O. Haenssler
+++ University of Oldenburg, Germany

Frequently Asked Questions

Performance

Why isn't the PICOSCALE **measurement range limited to half the laser's wavelength like in the interferometers I know?**
We use a laser modulation/demodulation technique that yields quadrature signals. Consequently, the direction of motion becomes unambiguous and the dynamic range covers twelve orders of magnitude (picometers to meters).

Can I do differential measurements?
Yes, the Michelson principle allows determining differential displacements of two targets with a single sensor head! You find it ready-to-use in our portfolio. Differential measurements are beneficial, because air fluctuations are suppressed and position noise can be significantly lower.

I have an external device...how can I achieve synchronous data acquisition with the PICOSCALE**?**
The **PICO**SCALE features versatile trigger functionality and you can use the device as master or slave for synchronization. You may also want to make use of one of the analog-to-digital inputs of the interferometer, which are sampled synchronously with position data.

In what environments can I use the sensor heads?
As the sensor heads are very compact, completely electronic-free and only emit a few micro-watts of optical power, that are routinely used in ultra-high vacuum or cryogenic environments and can be baked out. For machine shop applications or other harsh environments, the optical fibers can be equipped with stainless steel protection tubing in order to increase robustness.

Handling

The standard fiber length of the sensor heads is 1.5 meter. Can I extend that?
The **PICO**SCALE operates with telecom wavelengths where losses in optical fibers are almost negligible. You can use long fiber patch cables (contact us to find the right one) to extend the length almost arbitrarily. Thus, controller and sensor heads can be set up far apart from each other.

What do I need to consider regarding the target reflectivity?
Due to the Michelson principle, target reflectivity is not crucial at all and the **PICO**SCALE always measures in single-path mode. Mirrors or retro-reflectors are typical, but you may use polished metal or other surfaces as well. If you are not sure if your target works out, contact us and we will test it for you. Please also consider our loan service, where you can convince yourself of the **PICO**SCALE.

How can I use the Interferometer in a feedback loop?
The **PICO**SCALE provides several interfaces to extract data. AquadB data are easily accessible as well as a serial data protocol. You may also output an analog voltage proportional to a position value. If you want to control SmarAct positioners, we highly recommend the SmarAct SI interface, which provides a direct link to the **MCS**2, for example. Furthermore, you may also want to close the loop in software – we provide libraries and software snippets for C/C++, LabVIEW, python, and others.
Please note: As an outstanding feature, angle calculation is realized inside the **PICO**SCALE in real time and feedback loops for angle control are possible without additional software running on a PC!

Service & Costs

How do I learn about the price of a PICOSCALE **system?**
Despite it exceptional performance you will find the pricing very competitive. Because of the many configuration options the excact price will strongly depend on your precise application, as we always want to offer optimal equipment. Do not hesitate to contact us and benefit from the expertise of our technical consultants.

I only need the PICOSCALE **for a limited time... and how can you help me with my budget constraints?**
No problem. We offer a loan service where you get the device only as long as you need it. If you consider keeping it afterwards, the loan fees will be subtracted from the price.

What can I do if the PICOSCALE **and its accessory do not fit exactly to my application?**
Customization of our products is our daily business and ranges from slight modifications of existing products to completely new developments. SmarAct is proud to have a large team of technical sales engineers and application specialists for rapid prototyping. Since we develop and produce all of our products in house, we can provide best possible time to market.

Can I benefit from your experience in fields of metrology?
We have been developing and applying metrology solutions for years. We are happy to share our ideas and knowledge with you to find the best solution for your metrology task.

Where can I find more information?
Please browse our webpage, check out the application notes and specification sheets or enjoy the videos. If you still miss any information, do not hesitate to contact us!

Your Partner for High Precision in Positioning and Metrology.

SmarAct offers high-performance solutions for challenging positioning and measurement tasks on the micro- and nanometer scale. The portfolio ranges from 1D stages, easy-to-use control systems to complex 6D positioning systems. Our optical metrology solutions are based on laser interferometry and enable high precision vibration and displacement measurements.

SmarAct is located in Oldenburg (Germany) and was founded in 2005 as a spin-off from the University of Oldenburg. In the last 15 years we have grown to a company with more than 190 employees that take care of the complete production process from development and design to production and assembly.

Our Services

Standard products. We serve the high-end market with a wide range of standard products with exceptional performance. Please visit our website for a complete overview.

Custom solutions. We have extensive experience in developing custom solutions according to your specific requirements, no matter whether it is a highly complex or a high-volume OEM positioning system.

Rental Service. You only need a SmarAct product for a few weeks? Many of our positioning and metrology systems can also be rented.

Measurement Service. You want us to perform motion or vibration analysis? Benefit from the latest equipment and expertise and outsource your measurements.

Get in contact

To support you in choosing the best solution for your positioning and measurement tasks, we have a team of highly qualified technical sales and support engineers with expertise that also covers your field of application, such as physics, material science, semiconductors, optics, microscopy, life science and micro assembly. Take the next step and contact us to discuss your application.

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SmarAct develops high-performance solutions for handling and positioning in the micro- and nanometer range. The broad product portfolio - from single stages to complex parallel kinematics, miniaturized robots and easy-to-use control systems - is completed by sophisticated measuring equipment based on powerful laser interferometers.

We serve high accuracy positioning and metrology applications in research and industry within such fields as optics, life sciences, micro-assembly, semiconductors and microscopy. Maintaining the complete production in-house allows a high level of customization.

Thus, we always provide you with the optimal individual or OEM solution.

www.smaract.com

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