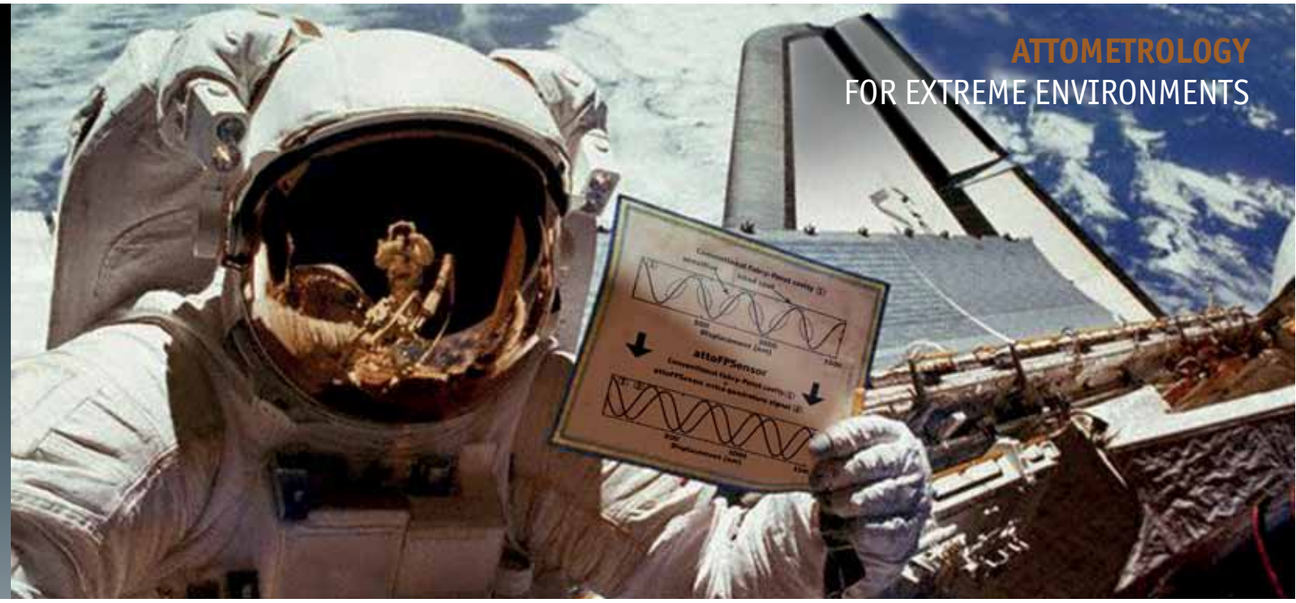
ATTOMETROLOGY
FOR EXTREME ENVIRONMENTS



ATTOMETROLOGY
FOR EXTREME ENVIRONMENTS

attoFPSensor

Interferometric Displacement Sensor

attocube systems AG | Königinstrasse 11a (Rgb) | D - 80539 München | Germany
Tel.: +49 89 2877 809 - 0 | Fax: +49 89 2877 809 - 19 | info@attocube.com
www.attocube.com

Brochure version: 2011 - 01

attocube systems
explore your nanoworld

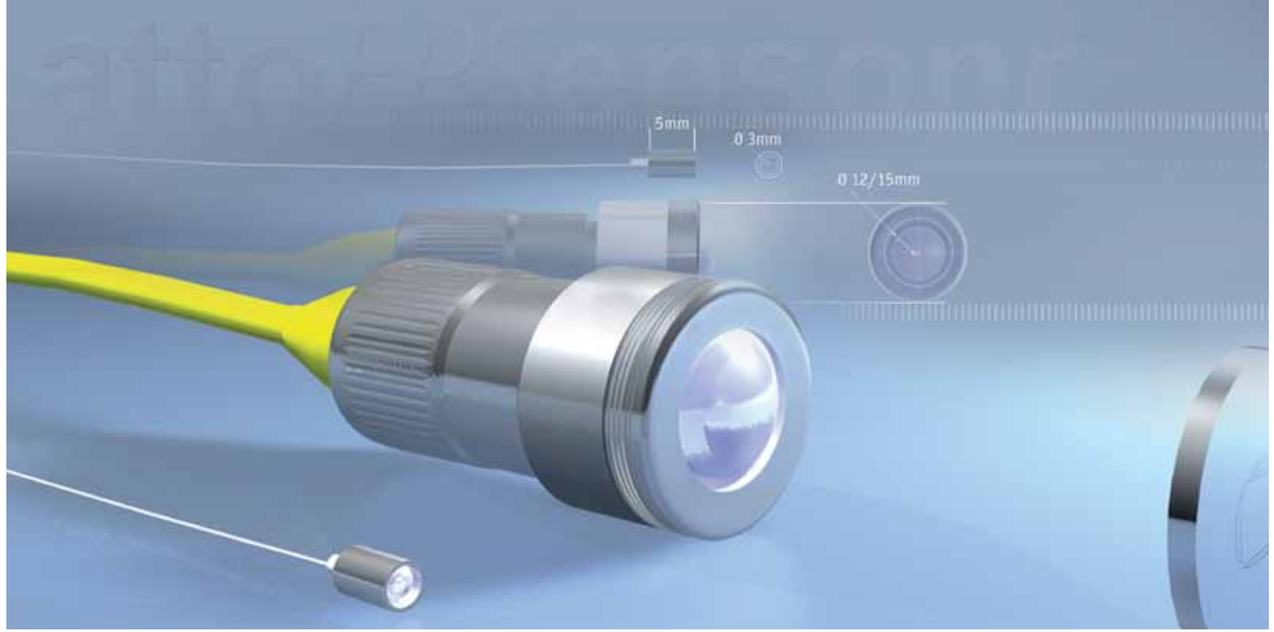
attocube systems
explore your nanoworld

01

ULTRA-HIGH PRECISION DISPLACEMENT SENSOR

MEASURE DISTANCES WITH STUNNING PICOMETER RESOLUTION AND MHz SAMPLING RATE

Ever increasing industrial quality standards and the scientific need for traceable measurement tools are the world into which attocube has successfully engineered its fiber-optic displacement sensor. Its ultra-compact design and compatibility with extreme environments opens up new possibilities and applications for interferometric measurements. The attoFPSensor has a stunning resolution of up to 30 pm even over large distances while offering sampling rates as high as 12.5 MHz and an absolute accuracy of ±0.5 ppm. These capabilities are unheard of in industrial metrology and drive new applications in interferometric displacement and vibrometry measurements under harsh conditions in research and industry. With applications ranging from closed-loop scanning to square-foot manufacturing and displacement detection in turboshaft- and gas engines, attocube is creating today's solutions for tomorrow's problems.



Metrology has thrived at the interface between science and manufacturing and is one of the key components to satisfy the demand of modern industry to meet international quality standards and to provide traceable measurements for scientists around the world.

While laser-interferometry has long been used as a standard metrology tool, there has been a technology gap in the availability of ultra-precise miniaturized displacement sensors for the operation in harsh environments, ranging from space and aerospace applications to the operation in nuclear power plants and research labs.

attocube has closed this gap by engineering a single-fiber based sensor, smaller in size than any other interferometer on the market while offering a performance superior to most industrial sensors currently available. Based on an atto**cube** patented technology, the attoFPSensor allows absolute displacement measurements with an accuracy of ±0.5 ppm and a resolution of up to 30 pm.

Truly accurate
All measurements performed with the attoFPSensor can be traced to international length standards and are therefore truly accurate. An internal wavelength reference cell (enhanced stability option) enables tracing of measurements to standards of NIST, PTB, NIM, NRLM, and other national standards organisations worldwide.

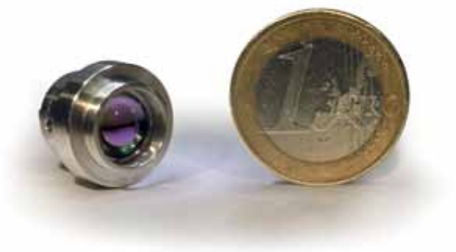
Ultra fast
With sampling rates of up to 12.5 MHz, the attoFPSensor can cope with displacement feedrates as high as 1 m/s without impairing accuracy or repeatability. The high sampling rate makes the sensor also ideally suited for high-frequency, low-noise vibrometry measurements in the MHz range.

Extremely stable
Available in different configurations, the stability and repeatability of the attoFPSensor is up to 50 billionth of the sensor-sample separation, equal to 50 nm at 1 m axis length.

Miniature size
Due to its material composition, its manufacturing precision, and miniature size, the attoFPSensor can be used in all kind of extreme conditions such as low or high temperature, high magnetic field, high electric field, or ultra high vacuum.

In addition to those benefits, the attoFPSensor can be equipped with up to 9 axes, all working simultaneously. Due to a proprietary technique, each axis allows a tilt of over ±0.4°, enabling plug-and-measure applicability of the sensor without the need for painstaking alignment.

THE SMALLEST INTERFEROMETRIC SENSOR ON THE MARKET



PRODUCT KEY FEATURES

> up to 30 pm resolution
> ± 0.5 ppm accuracy
> 12.5 MHz sampling rate
> miniaturized sensor design
> ultra fast electronics
> ultra low laser power
> single fiber based
> compatible with ultra-high vacuum (UHV) and cryogenic environment

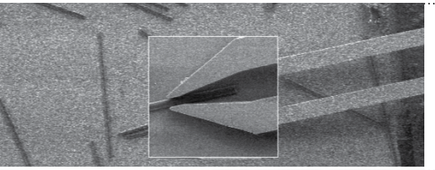
BENEFITS

> maximize machine tool performance
> improve your process control
> measurements in extreme environments
> certify machine tool accuracy
> ultra-low thermal drift
> no electrical connections
> sensing of displacement direction
> “plug and measure” (high tolerance on mirror adjustment)

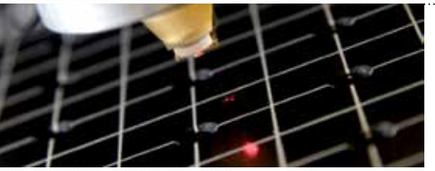
02
ATTOCUBE'S FIBER OPTIC SENSOR
ENABLING NEW INDUSTRIAL AND RESEARCH APPLICATIONS

INDUSTRIAL MICROMACHINING
- Ultra-fast, absolute position control of cutting tools
- closed-loop sample motion with highest feedrates
- fast optical inspection of work pieces with nm accuracy
- circularity and straightness analysis of work pieces
- in-situ wear & tear and vibration measurements of high-speed cutting tools

ULTRA-HIGH FREQUENCY POSITION DETECTION IN AEROSPACE INDUSTRY
- axial runout detection at MHz sampling rate with nm resolution
- blade clearance and deformation/growth detection
- vibration level measurements
- circularity analysis
- clearance measurement under extreme environment (heat)



STATE OF THE ART NANOTECHNOLOGY APPLICATIONS
- Multi-axis wafer stepper positioning
- Interferometric table for lithography applications in Scanning Electron Microscopes
- Highest-accuracy positioning of manipulators, probes, and other tools
- Vibrometry measurements on quantum optomechanical resonators and other micro- or nanometer sized objects



GENERAL INDUSTRIAL APPLICATIONS
- Optical roughness detection
- Profilometry and surface topography measurements
- Portable calibration and routine performance checking of machines
- Straightness and circularity measurements
- Traceable absolute distance measurements

RESEARCH APPLICATIONS
- Measurements of thermal expansion of low expansion materials
- Interferometric measurements of seismic waves
- Absolute force detection for tensile studies over large ranges using AFM cantilevers
- Highest-accuracy active positioning of lenses and samples in x-ray, synchrotron, and visible-light optics applications

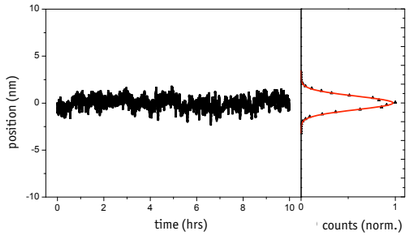
CLOSED-LOOP NANOPOSITIONING FOR EXTREME ENVIRONMENTS
- Sample / sensor positioning with highest stability & resolution
- Stitching functionality in lithography and scanning applications
- Large range closed-loop scanning with no hysteresis or creep
- High speed nanofocusing
- Coarse positioning for AFM, STM, SNOM,...

ULTRA-HIGH SPEED, LOW-NOISE CONTROL ELECTRONICS AMC500

Highest Performance for Sophisticated Applications

Tailored to work seamlessly with the attoFPSensor family, attocube systems has developed the state of the art metrology controller AMC500. The AMC500 allows simultaneous operation of up to nine sensor axes, where one axis can be used for laser wavelength stabilisation to 50 parts per billion (enhanced stability option). The AMC500 records displacement data with a sampling rate of 12.5 MHz and allows the user to process and ouput this data in real-time via digital high-speed serial, A-quad-B, and low latency USB ouput interfaces. An optional environmental compensation tops off the functionality of the AMC500 and enables most accurate measurements at various environmental conditions.

- Multi-axis metrology controller with 12.5 MHz sampling rate
- Laser wavelength stabilisation to 50 ppb (enhanced stability option)
- Optional environmental compensation
- Real-time digital sensor ouputs

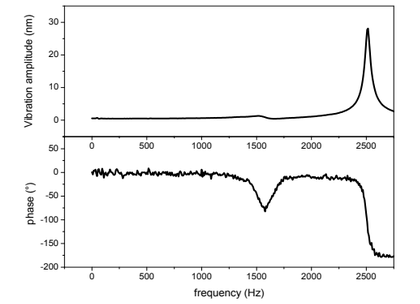


Repeatability	
cavity length [mm]	SD [pm]
20	345
60	530
110	1035

Displacement sensing of a 60 mm long Titanium reference cavity, temperature stabilized at 4 K. The standard deviation (SD) in position is 530 pm as measured with a 100 Hz bandwidth. A similar but shorter cavity of 20 mm length leads to a SD of only 345 pm (attocube application labs 2010).

attoFPSensor stability measurements

In this application, the stability of the attoFPSensor signal was measured using different Titanium cavities, temperature stabilized to 4 K. Due to the reduced coefficient of thermal expansion at low temperature, a low pressure environment, and a temperature stability in the mK range, the (low temperature) Titanium cavities provide a reference in length approximately 10 times more stable than a corresponding Zerodur cavity at ambient conditions. The plot to the right shows displacement data recorded during a 10 hour period of time in a 60 mm cavity, demonstrating the drift stability of the attoFPSensor. The standard deviation for position sensing in this cavity corresponds to 530 pm recorded with a 100 Hz bandwidth, while it can be as low as 345 pm for a 20 mm cavity (see table).



Vibrometry measurement of a prototype xyz positioner measured using the attoFPSensor and a piezo for excitation. The excitation amplitude was approx. 0.5nm.

attoFPSensor for vibrometry measurements

In this application, the attoFPSensor was used as a tool to determine eigenmodes and associated eigenfrequencies of various work pieces and mechanical setups. The data to the right demonstrate the suitability of the sensor for this type of application by determining the resonance frequency of a prototype xyz positioning stack. In this specific case, the stack was excited by a piezo element and the response function in vertical direction was measured with the attoFPSensor. While the amplitude is already a good indicator as to whether or not resonance occurs, the phase relation between excitation and detection signal is the most robust measure of a resonance condition. In this case, the phase shift of 90°/180° at approximately 2.5 kHz indicates the first normal-mode resonance of this mechanical system. For the excitation of the stack, a drive amplitude of only 0.5 nm was used.

03
SPECIFICATIONS

attoFPSensor SERIES

attoFPSensor model	FPS300	FPS300/ES (enhanced stability)	FPS12500	FPS12500/ES (enhanced stability)
Sensor				
maximum bandwidth	300 kHz	300 kHz	12500 kHz	12500 kHz
sensor resolution				
vibrometry	30 pm	30 pm	30 pm	30 pm
position detection	250 pm	250 pm	250 pm	250 pm
sensor repeatability				
at 20 mm cavity length[1]	10 nm	1 nm	10 nm	1 nm
as fraction of cavity length[1]	500 ppb	50 ppb	500 ppb	50 ppb
sensor working distance	> 10 cm	> 10 cm	> 10 cm	> 10 cm
linearity	± 2 nm	± 2 nm	± 2 nm	± 2 nm
absolute accuracy	± 15 ppm	± 0.5 ppm	± 15 ppm	± 0.5 ppm
max. displacement velocity	0.0005 m/s	0.0005 m/s	1 m/s	1 m/s
alignment accuracy	± 0.4 °	± 0.4 °	± 0.4 °	± 0.4 °
environmental compensation	on request	on request	on request	on request
Laser				
laser source	DFB laser	DFB laser	DFB laser	DFB laser
wavelength	1550 nm	1550 nm	1550 nm	1550 nm
wavelength stabilization	no	yes	no	yes
laser power	75 typ. µW	75 typ. µW	75 typ. µW	75 typ. µW
Physical Properties				
sensor head dimensions				
smallest	Ø 3 mm, l = 6 mm	Ø 3 mm, l = 6 mm	Ø 3 mm, l = 6 mm	Ø 3 mm, l = 6 mm
standard	Ø 15/12 mm, l = 12 mm	Ø 15/12 mm, l = 12 mm	Ø 15/12 mm, l = 12 mm	Ø 15/12 mm, l = 12 mm
sensor head material	stainless steel, titanium	stainless steel, titanium	stainless steel, titanium	stainless steel, titanium
optical fiber	Ø 250 µm, plastic or metallic coating	Ø 250 µm, plastic or metallic coating	Ø 250 µm, plastic or metallic coating	Ø 250 µm, plastic or metallic coating
temperature range	mK .. 373 K (100 °C)	mK .. 373 K (100 °C)	mK .. 373 K (100 °C)	mK .. 373 K (100 °C)
pressure range	$1x10^{-10}$ mbar .. 10 bar	$1x10^{-10}$ mbar .. 10 bar	$1x10^{-10}$ mbar .. 10 bar	$1x10^{-10}$ mbar .. 10 bar
operation and mounting	any direction /LT/HV/UHV	any direction /LT/HV/UHV	any direction /LT/HV/UHV	any direction /LT/HV/UHV
compatibility options				

[1] cavity length = working distance (WD) + lens/fiber separation

HIGH-SPEED PERFORMANCE

SETTING NEW STANDARDS IN REPEATABILITY AND RESOLUTION

repeatability vs working distance

working distance (WD) [cm]	sensor repeatability (standard) [nm]	sensor repeatability (enhanced stability) [nm]
0.5	5.0	1.0
1	7.5	1.0
5	25	2.5
10	50	5.0

interface resolution vs velocity

target velocity [m/s]	resolution HSSL[1] absolute 32 bit, 400 kHz [nm]	resolution USB[2] absolute 32 bit, 400 kHz [nm]	resolution A-quad-B[1,3] incremental 400 kHz [nm]
0.00001	0.25	0.25	0.25
0.0001	0.25	0.25	0.25
0.001	0.25	0.25	2.50
0.01	0.25	0.25	25.0
0.1	0.25	0.25	250
1	0.25	0.25	2500

[1] real-time ouput
[2] USB latency 5 ms typical
[3] available with clockrates up to 3.5 MHz on request