PICOSCALE Vibrometer System Controller PV-CTRL-V1.0

SmarAct | metrology

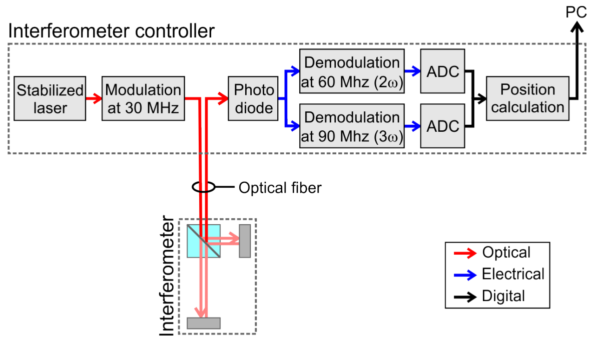

Figure 1. *Interferometer signal flow.*

The **PICO**SCALE *Vibrometer* contains two controllers, the system controller and the stage controller:
The system controller hosts all the necessary optical components and electronics to generate the IR laser beam and to detect the interference signal. Furthermore, it contains the circuitry to convert the measured interferometric data into a position signal and to extract its amplitude and frequency.
The stage controller contains the electronics to operate the XYZ positioning stage in closed-loop. In addition, it provides access to internal system signals and contains a power amplifier to drive the shaker stage.

This document contains the general specifications of the system controller. Refer to the dedicated specification sheet for a detailed description of the performance limitations of the system controller.

INTERFEROMETER CONTROLLER

The system controller includes an interferometer controller which is largely identical to the **PICO**SCALE *Interferometer* controller from SmarAct Metrology GmbH & Co. KG. The differences are that the system controller contains only one optical channel (instead of 3) and that the laser output power is 3 times higher. Figure 1 shows the basic design of the interferometer controller. The stabilized IR laser is modulated and sent to the sensor head via a single mode optical fiber. The sensor head contains a Michelson interferometer and allows to focus the measurement laser beam onto a sample to measure its displacements. The interference signal is routed back to the controller through the same optical fiber. Here, the signal is measured by a photo diode, demodulated and processed within a field-programmable gate array to obtain displacement.

Table 1 and Table 2 contain the specifications of the interferometer and system controller.

Table 1. *Interferometer specifications.*

Property	Value
Interferometer controller type[1]	**PICO**SCALE
IR laser: Wavelength [nm]	1550
IR laser: Power [mW]	< 0.9
Pilot laser[2]: Wavelength [nm]	650
Pilot laser: Power [mW]	< 0.4
Displacement resolution[3] [pm]	< 1
Noise floor[4] [pm/$\sqrt{\text{Hz}}$]	< 1
Max. sampling rate[5] [MHz]	10

[1] See **PICO**SCALE *Interferometer* specification sheets, available at SmarAct Metrology GmbH & Co. KG, for further information.
[2] A pilot laser is coupled into the optical fiber to facilitate an easy positioning of the IR measurement laser onto the sample.
[3] When analyzing periodic displacements in the frequency domain.
[4] Above 10 kHz and in combination with the PS-SH-F03 sensor head. See the **PICO**SCALE *Interferometer* specification sheet on noise, available at SmarAct Metrology GmbH & Co. KG, for detailed information.
[5] The maximum measurement bandwidth is 2.5 MHz.

Table 2. *System controller specifications.*

Property	Value
AC Power Supply: Voltage [V]	100 - 240
AC Power Supply: Frequency [Hz]	50 - 60
Input current (at 230 V) [A]	$<$ 0.5
Fuse (slow blow) [A]	2.5
Environmental temperature [°C]	15 - 30
Environmental humidity [%]	5 - 80
Storage temperature [°C]	0 - 50
Altitude [m]	$<$ 2000
Dimensions W x L x H [cm]	33 x 27 x 7.3
Weight [kg]	3.5

OPTIC FIBER ATTENUATOR

The system controller is supplied with a 3 dB fiber optic attenuator that is mounted directly onto the fiber socket on the front panel. The sensor head is connected to the attenuator. Only for very poorly reflecting surfaces, the attenuator can be removed such that the sensor head can be connected directly with the system controller. In absence of the attenuator the photo diode will not be damaged, even at high signal levels. However, if the signal quality during adjustment exceeds 300, the attenuator should always be installed to avoid saturation of the photo diode within the system controller.

LASER WAVELENGTH STABILIZATION

Since the measured position depends directly on the emitted wavelength, a constant laser wavelength is essential. A distributed feedback (DFB) laser is used which has a spectral width of ≈ 10 fm. The wavelength is measured by guiding a part of the laser light through a gas reference cell while measuring the transmitted signal. This hydrogen cyanide absorption cell is extremely insensitive to environmental parameters like temperature, humidity, pressure and electro-magnetic fields and thus offers a stable standard to determine the wavelength within a range of less than 1 pm. By regulating the laser chip temperature the wavelength is locked to an absorption line of the gas (according to the standard NIST SRM2519a).

QUADRATURE DETECTION

In a standard Michelson interferometer, the intensity of the interference signal depends sinusoidally on the displacement of the sample. Due to the symmetry of the sinusoid, the direction of displacement cannot be determined. Furthermore, the sensitivity (change in signal intensity due to a change in sample position) is not constant during displacement but will be highest at the zero crossing of the sinusoid. Thus, for high-resolution vibration measurements, the standard Michelson interferometer is not ideal. To overcome these limitations, the **PICO**SCALE *Interferometer* employs phase modulation of the laser light by modulating the injection current of the laser diode. By using appropriate demodulation techniques [1,2], it becomes possible to extract a quadrature signal which is composed of two sinusoidal waves that are phase-shifted by 90° (Figure 2). Constant movement of the sample produces a circle in a two dimensional representation, a Lissajous plot. When both signal components are plotted in a single figure (Figure 2 bottom-right) it can be seen that all regions of low sensitivity in one signal are compensated by high sensitivity regions in the other. A constant high sensitivity is maintained during motion of the sample. Furthermore, the phase relationship between the two components allows to unambiguously determine the direction of motion. While an increasing relative position of the sample leads to a clockwise rotation of the X-Y vector, a decreasing position leads to a counter-clockwise rotation. Thus, sinusoidal phase modulation interferometry is perfectly suited for high-resolution position measurements.

[1] Sasaki. Sinusoidal phase modulating laser diode interferometer with feedback control system to eliminate external disturbance. Optical Engineering, 29, 1990.
[2] Suzuki *et al.* Laser-diode interferometer with a photothermal modulation. Applied Optics, 38, 1999.

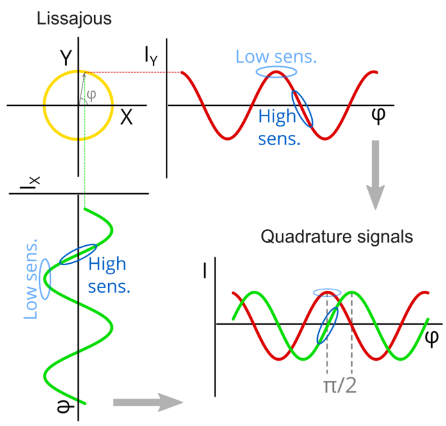

Figure 2. *Quadrature signal detection. Phase modulation of the laser is employed to obtain two interference signals in quadrature (in red and green). This allows to compensate the regions of low sensitivity (light blue) in one signal with regions of high sensitivity (dark blue) in the quadrature signal. Thus, a high sensitivity is maintained at any position. The combined signals are usually represented as a 2D "Lissajous" plot (yellow).*

SIGNAL GENERATOR

The system controller is equipped with a signal generator which is implemented in the field-programmable gate array. The signal generator can be set to operate at a constant frequency or to sweep the frequency from a lower to an upper limit. The output of the frequency generator is available through the stage controller and can be used to electrically excite a sample. Table 3 shows the output specifications.

Table 3. *Specifications of the signal generator.*

Property[1]	Value
Frequency range [kHz]	0.001 - 2500
Frequency resolution[2] [Hz]	1
Frequency accuracy [ppm]	$< \pm 30$

[1] Further specifications of the analog output signal can be found in the specification sheet of the stage controller.
[2] Limit set by control software, the internal resolution is much higher.

LOCK-IN AMPLIFIER

The system controller employs 2 methods to extract the amplitude and phase of the vibrations from the interferometric position measurements. For single point measurements, the position data is converted into the frequency domain by a Fourier transformation (FFT). From the FFT graph, which can contain millions of data points, the amplitude and phase can be read out at the desired frequency. For megapixel imaging of vibrations this approach is less convenient because of the huge amounts of data that will have to be recorded. Therefore, the system controller contains a digital lock-in amplifier. The lock-in amplifier is fed with the position data and extracts only two parameters, the amplitude and phase at one defined frequency (reference frequency), which thus leads to an enormous reduction of data.
In brief, a lock-in amplifier works as follows. The input signal is the position data extracted from the interferometric measurements. When the sample is excited at a fixed frequency, the position signal will be modulated with this excitation signal (this modulation is not to be confused with the aforementioned modulation of the laser wavelength). The calculation principle of a *single* lock-in amplifier is based on the demodulation of the input signal with a single reference signal. This reference signal is the same signal which is used to excite the sample.
To demodulate the position signal, it is multiplied with the sinusoidal reference signal. The output of the demodulation contains two components, a DC and an

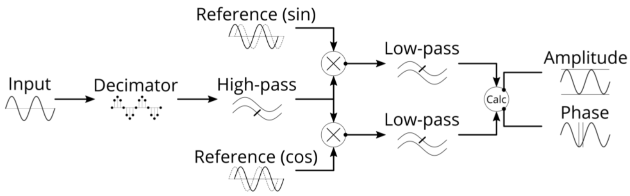

Figure 3. *Digital dual-phase lock-in amplifier as implemented in the **PICO**SCALE Vibrometer. Depending on the frequency of the reference signal, the position signal (Input) can be decimated first to reduce the input sampling rate. Then, the signal is high-pass filtered to remove any offset that would otherwise affect the calculation of the amplitude and phase. The high-pass filtered signal is multiplied with the two quadrature references signals (sine and cosine) that are set at the frequency of interest. Both products are low-pass filtered to obtain the orthogonal amplitude components from which the amplitude and phase are readily obtained.*

AC (which contains a peak at twice the reference frequency). The AC component is removed with a low pass filter. The remaining DC component is proportional to:

$$DC \propto A \cdot \cos(\theta) \quad (1)$$

where A and θ are the amplitude and phase of the vibrations respectively.

With a single lock-in amplifier it is difficult to separate the amplitude from the phase, therefore, the **PICO**SCALE *Vibrometer* contains a *dual-phase* lock-in amplifier (Figure 3). Here, the input signal is multiplied with two reference signals, a sine and its quadrature, a cosine. From the dual phase lock-in amplifier 2 signals are obtained from which the amplitude A and phase θ of the vibration can be separated with trigonometry.

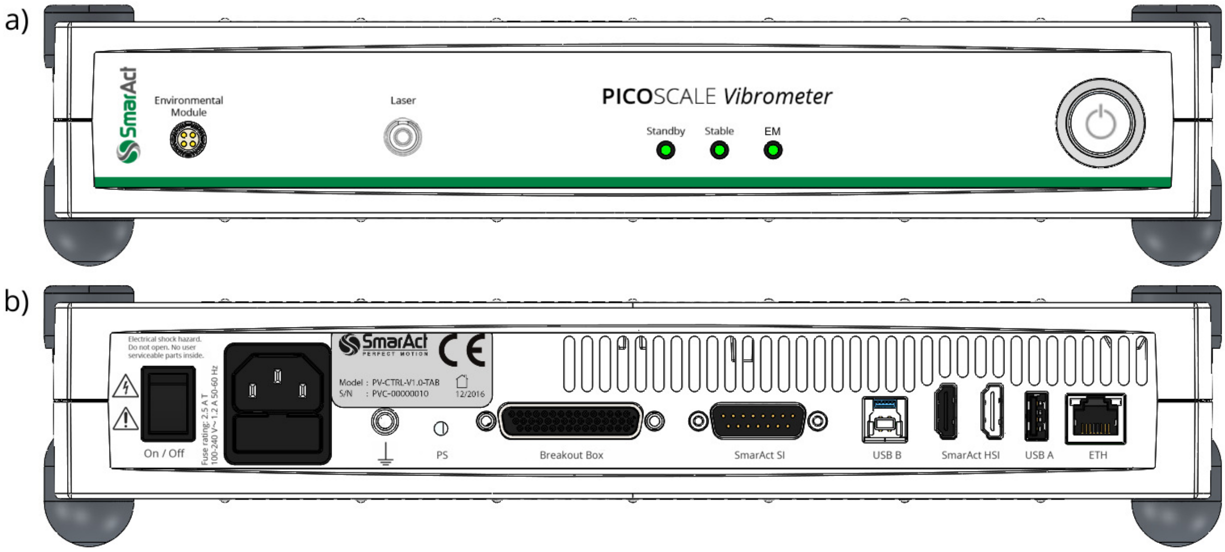

Figure 4. *a) Front and b) rear panel of the system controller.*

CONNECTORS

The system controller contains multiple connectors to connect it to the other components of the **PICO**SCALE *Vibrometer*. The front panel, shown in Figure 4a, contains, from left to right:

- LEMO 4 pin connector '*Environmental Module*', female, to connect a SmarAct GmbH environmental module (reserved for future use).
- Optical FC/APC connector '*Laser*', female, to connect with the sensor head via a fiber optic attenuator and a single mode patch cable.
- LED '*Standby*', indicates when the device is in standby mode.
- LED '*Stable*', indicates when the laser wavelength is stable.
- LED '*EM*', indicates if an active connection to an environmental module is established (reserved for future use).
- Power button to switch the stage controller on or off (standby).

The system controller rear panel, shown in Figure 4b, contains, from left to right:

- Main power switch '*On/Off*', to power up the device.
- Power supply socket, including a fuse.
- Ground connector '⏚', which can be used to ground external devices.
- Push-button '*PS*', to update the firmware of the device (see the firmware update section for more details).
- D-Sub 44 connector '*Breakout Box*', female, to connect with the stage controller.
- D-Sub 15 connector '*SmarAct SI*', male (reserved for future use).
- USB Type B connector '*USB B*', to connect with the PC.
- Two HDMI connectors '*SmarAct HSI*' (reserved for future use).
- USB Type A connector '*USB A*', to update the firmware of the device (see the firmware update section for more details).
- Ethernet connector '*ETH*' (reserved for future use).

ORDER CODES

The order codes of the system controller and its accessories are given in Table 4.

Table 4. *Order codes of the system controller and accessories.*

Order code	Description
PV-CTRL-V1.0-TAB	**PICO**SCALE *Vibrometer* system controller including fiber optic attenuator
FA03T-APC	Fiber optic attenuator 3 dB

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SmarAct Metrology GmbH & Co. KG develops sophisticated equipment to serve high accuracy positioning and metrology applications in research and industry within fields such as optics, semiconductors and life sciences. Our broad product portfolio – from miniaturized interferometers and optical encoders for displacement measurements to powerful electrical nanoprobers for the characterization of smallest semiconductor technology nodes – is completed by turnkey scanning microscopes which can be used in vacuum, cryogenic or other harsh environments.
We maintain the complete production in house for a high level of customization so that we can always provide you the optimal individual or OEM solution. We also offer feasibility studies, measurement services and comprehensive support to accompany you along your projects.

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