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Ultra-precise position and vibration analyses using Fabry-Pérot interferometry

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Abstract
Measuring displacements with nanometer accuracy, as well as vibrations with amplitudes of few picometers, on a large variety of materials is very challenging as it exceeding the capabilities of most commercially available measurement techniques. We present measurement results on different materials performed with attocube's Industrial Displacement Sensor (IDS) by matching the sensor head to the material and application. A unique feature of our system is the ability to accommodate advanced applications, for example in very constrained spaces and under extreme environmental conditions; we developed sensor heads, with a diameter smaller than 1 millimeter and suitable for temperature up to 400 °C. To demonstrate the flexibility of our interferometer system, we show results of displacement measurements realized on a water surface, we present vibration measurements on a micro-sized cantilever, and we show 3D profilometry measurements on a metal wire with a diameter of only 200 micrometers.

Interferometry, hydrostatic leveling system, vibrometer, profilometry

1. Context

We developed a compact fiber-based Industrial Displacement Sensor (IDS) which enables picometer displacements to be measured on a wide range of target materials, the sensor head needs to be matched to the material. Glass, plastic, ceramics, silicon, copper, steel, aluminum, silver or gold are just few examples of target materials on which position measurements can be realized. Working distances and angular tolerances depend on the surface reflectivity as well as which sensor head is used. Using a standard target, such as a retroreflector, the working distance starts directly after the sensor head and can exceed a range of 30 meters.

2. Measurement Results

The working principle of our Fabry-Pérot interferometer, details about interference contrasts, along with working ranges and angular alignment tolerances of several sensor heads, are explained in detail in the references [1] and [2]. In the following we report position as well as vibration analyses of three different target materials: water, cantilevers, and metal wires.

2.1. Water Surface

The first material under investigation is water. The opportunity to measure the surface movements of liquids opens the possibilities to realize unique applications in many scientific and industrial areas. One feasible application to measure on liquid surfaces could be realized, for example, in a hydrostatic leveling system [3].

The upper illustration in figure 1 shows the schematic setup for displacement measurements carried out on a water surface. The experimental setup included two focused sensor heads with a focal length of 40 mm fixed on an optical table, a cup of water, and an aluminum mirror. We focused on the water surface and were able to achieve a working range of few millimeters and angular tolerances of a few tenths of degrees. The results of the displacement measurement are depict on the lower plot in figure 1. We see that the first 0.714 seconds the water surface (blue curve) is only slightly wavering with 11.6 Hz in comparison to the stable position measurement of the mirror (red curve). Hitting the optical table between the two targets with a hammer, the water surface oscillates with a maximum deflection of approximately ± 20 µm. The zoom highlights that the two measurement arms show similar behaviors in the high frequency range for the first milliseconds after the excitation.

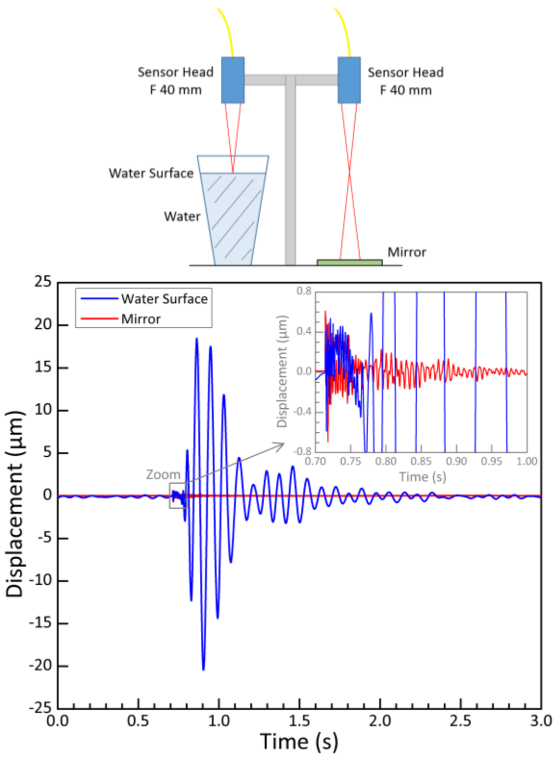

Figure 1. The top figure shows a sketch of the experimental setup to perform simultaneous displacement measurements on water and on a mirror. The bottom figure presents the measurement results. Here, the blue curve shows the water surface movements and the red curve represents the displacements of the mirror.

2.2. Micro-Sized Cantilever

The second material we analyzed was a micro-sized cantilever with the dimensions (t/w/l): 7 x 38 x 225 µm. Here, we measured the Brownian motion of this cantilever which is required in a large number of microscopy applications.

The experimental setup is shown in figure 2: The cantilever was fixed to a stack of attocube positioners to facilitate alignment with movements in x-, y-, and z-directions. For this application we used a sensor head with a focal length of 2.8 mm. The spot size is below 2 µm in diameter and we utilized a bandwidth of the digital signal output of 5 MHz (AquadB) to do Fast Fourier Transform (FFT) analysis in the high frequency range. After few seconds of the adjustment we received a high-contrast alignment signal from the cantilever.

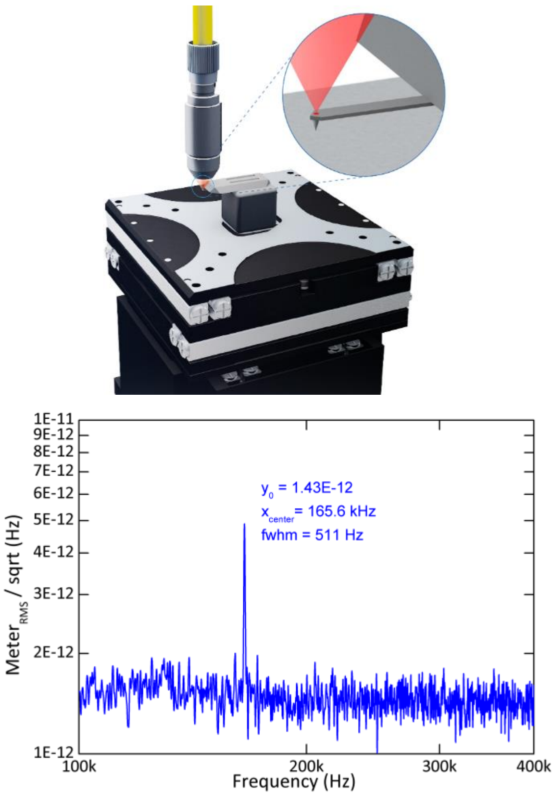

Figure 2. A stack of attocube x-, y-, and z-positioners was used to align the focused sensor head onto the micro-cantilever. The distance between the objective and the cantilever was about 2.8 mm. The bottom figure show the FFT analysis with the resonant frequency at 165.6 kHz.

The plot in figure 2 depicts the FFT result of the cantilever in a frequency range between 100 and 400 kHz. The cantilever shows a strong individual resonance peak. This resonance peak at 165.6 kHz is only excited due to Brownian motion as no other excitation was present in the setup. Moreover, the noise floor in the frequency range is around 2 pm/sqrt(Hz).

2.3. Metal Wire

The third material we examined was a metal wire with a diameter of only 200 µm. In many research and industrial applications, ultra-precise and contactless surface analyses are of major interest in order to guarantee the material quality as well as to detect even the tiniest contour deviations. We used the three synchronized interferometer axes to track the displacements and measure the surface morphology of the cylinder's surface.

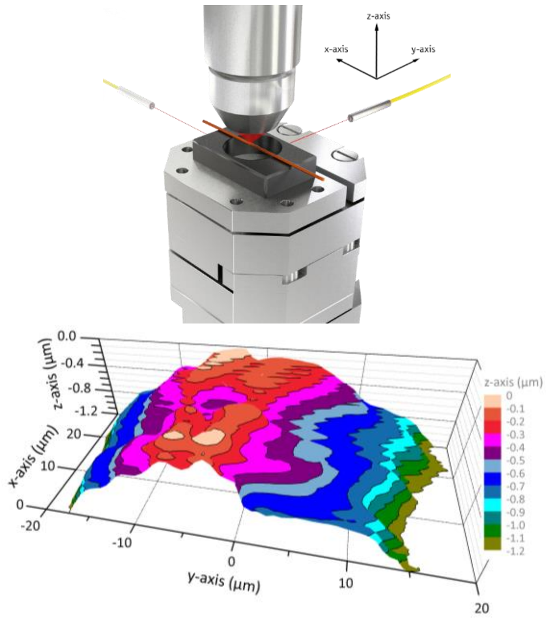

Figure 3. A metal cylinder was mounted on a 3D stack consisting of positioners and precision scanners. The cylinder's surface was measured from above (z-axis), all while its position (x- and y-axes) was simultaneously tracked. 3D color plot showing the surface morphology of a 200 µm diameter cylinder. Each color represents a 100 nm height step in z-direction.

The upper illustration in figure 3 shows the experimental setup employing three focusing sensor heads. From the top (z-axis) a sensor head a spot size of better than 2 µm was used to measure the surface of the cylinder. Perpendicular to this, two focusing sensor heads with a diameter of 1.2 mm were used to measure the relative displacements along (x-axis) and perpendicular (y-axis) to the cylinder's axial orientation. Hence, all three coordinates of each measured surface point were recorded, allowing for a full 3D reconstruction.

Using all interferometric axes simultaneously, a 3D surface of a separately measured 200 µm metal cylinder was constructed and the color plot in figure 3 shows the measured profile covering a 40 x 28 µm² area. Several deformations can be seen: In the center position the object profile clearly shows a dent on its surface with a depth of around 400 nm. In addition the diameter contour in the front part near x = 0 has a plateau over a length of approximately 10 µm.

3. Conclusion

We presented displacement measurement results of three different materials realizing three different applications: we tracked water surface movements, measured the resonant frequency of a micro-sized cantilever, and showed the 3D surface of a metal wire. These three examples demonstrate the capability of attocube's Industrial Displacement Sensor (IDS) to measure on a wide range of materials by adapting the sensor head to both material and application.

References

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