

## Fiber Probe with Interferometric Z-Measurement

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### Abstract

Increasing manufacturing accuracy requirements enforce the development of innovative and highly sensitive measuring tools. The recent introduction of optical fiber probes combined classical tactile measurement methods with optical read out and reaches measurement uncertainties as small as 0.1 micrometers. In this paper we describe an innovative way to measure the z-position of the fiber tip itself with high accuracy by using interferometry.

### Introduction

Increasing manufacturing accuracy requirements enforce the development of innovative and highly sensitive measuring tools. As industrial standards in many applications are still tactile measurement methods new tactile probes should work with minimum contact force. The recent introduction of optical fiber probes combines classical tactile measurement methods with optical read out and reaches measurement uncertainties as small as 0.1 micrometers, /1/.

### In-plane measurement

Fig. 1 shows the set-up of a fiber probe. The tip of the glass fiber is melted into the shape of a sphere. The glass fiber is fixed below a magnification optics with camera.

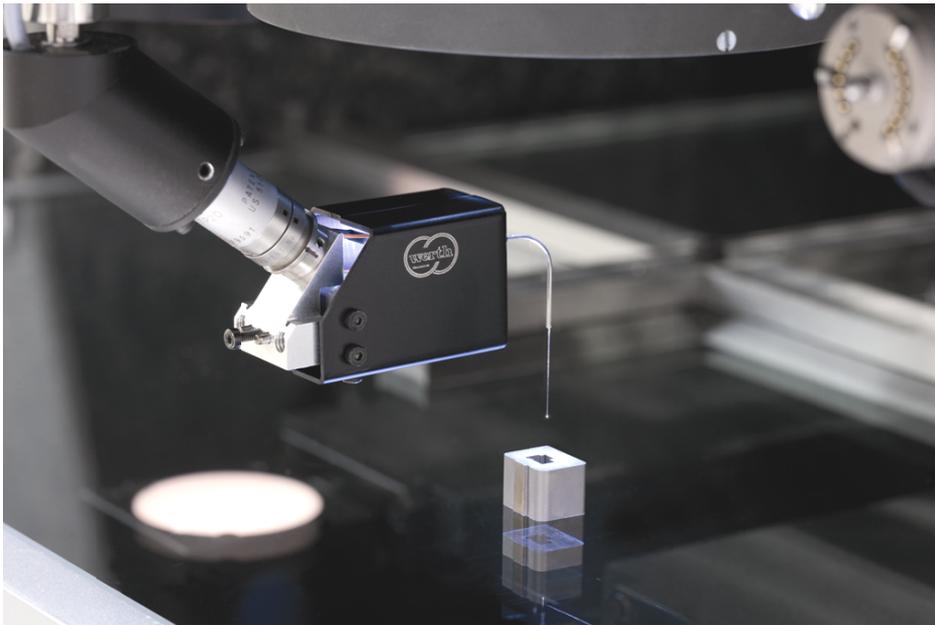


Fig. 1: Micro optical tactile probe based on a glass fiber (WERTH [1])

Due to the small diameter of the glass fiber (down to about  $10\ \mu\text{m}$ ) the contact force is minimal and can be as low as  $1\ \mu\text{N}$ . The optics observes the position of the tip of the probe, permanently. With classical image processing techniques the lateral position of the center of the sphere can be determined in realtime and with a measuring uncertainty of less than  $1\ \mu\text{m}$ , figure 2.

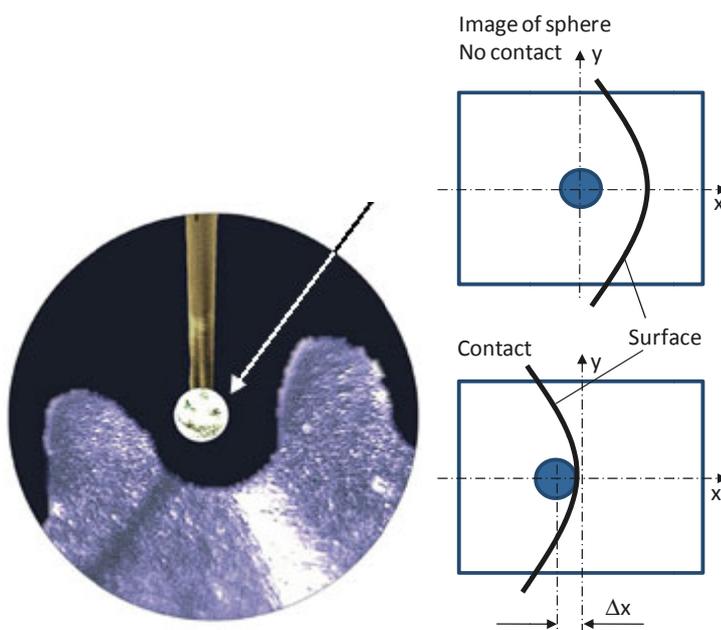


Fig. 2: Fiber probe with illumination and camera image

### Measuring of the z-position

However, the camera image cannot identify movements of the fiber probe in the vertical direction with sufficient accuracy. Therefore, different methods have been investigated to measure the z-position of the probe [3]. A laser speckle method and a stereo photographic method showed promising results, however other problems such as long time stability or geometric conditions hindered the application in 3D coordinate measuring systems. Today, a displacement sensor is used to measure the deflection of the fiber mount, fig. 3 [4]. This methods proved sufficient accuracy and measuring speed.

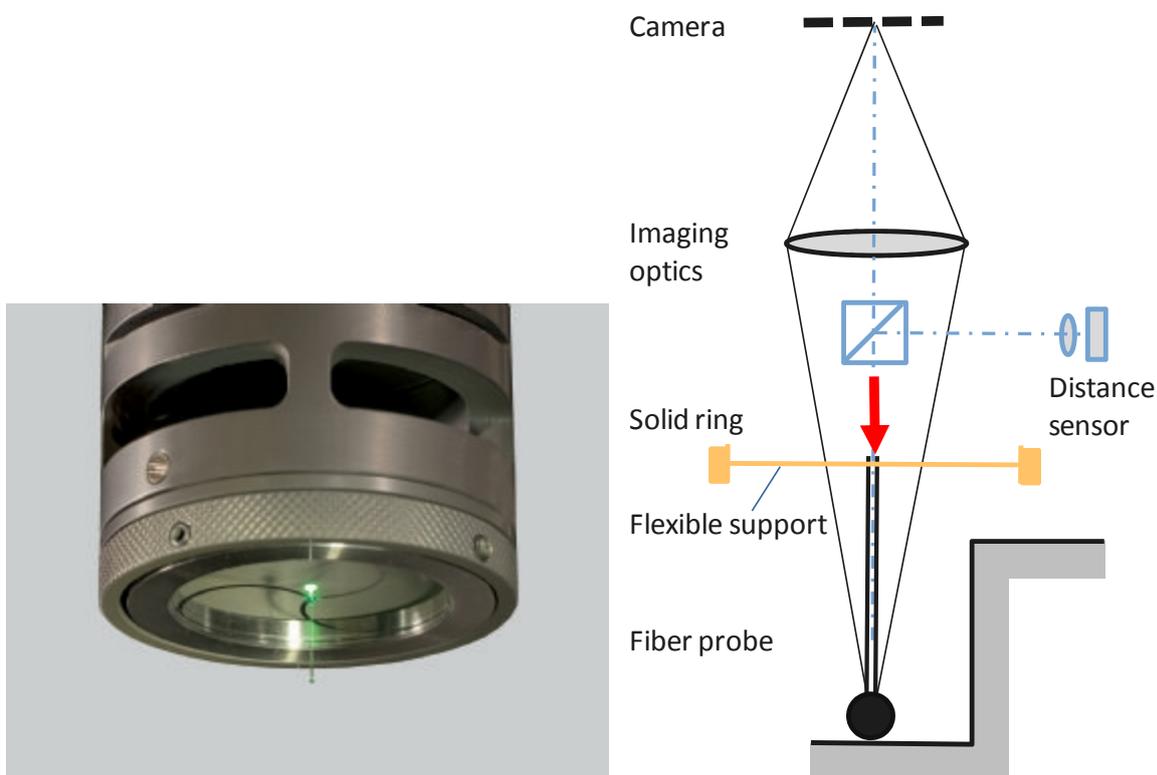


Fig. 3: Fiber mounting system [4] and z-measurement principle with distance sensor

This distance sensor delivers the z-position of the fiber mount (upper end of the fiber), but there still remains the risk that due to bending of the fiber or other effects this movement does not exactly represent the actual position of the sphere at the fiber tip.

Therefore, an interferometer set-up was designed, which measures directly the lower end of the fiber tip, fig. 4. The light of a diode laser is coupled into the end of the fiber. At the sphere the light is exiting the fiber in all directions. The magnifying optics collects part of this light and images it on the camera chip. A part of the laser light is split from the laser illumination

and directly guided to the camera as reference light. The interference between reference light and the light reflected from the sphere leads to a fringe pattern in the camera plane.

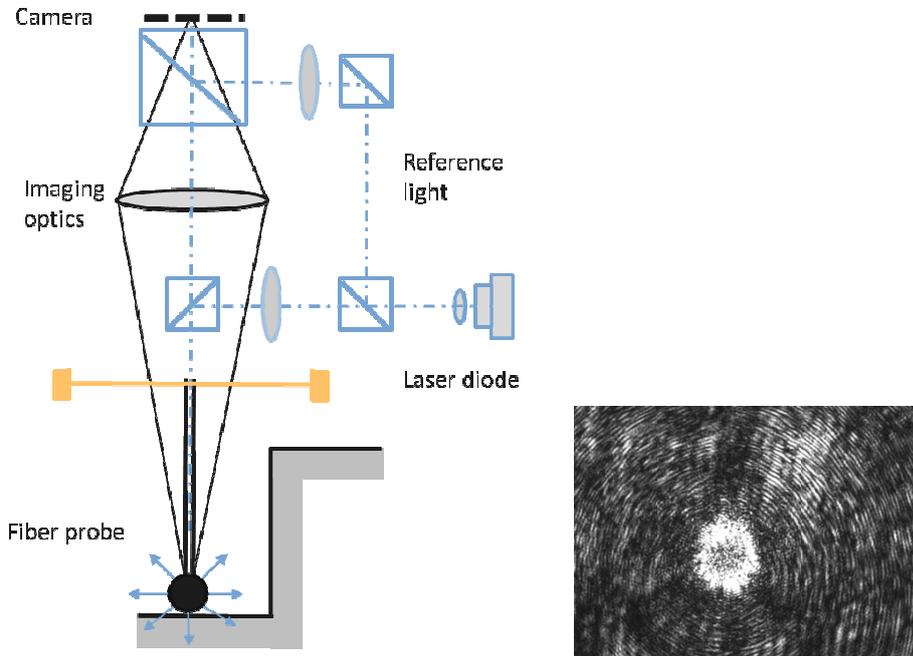


Fig. 4: Optical test set-up for interferometric measurement of the sphere position and speckle image of the sphere

The interference between the light from the sphere and the reference light creates a speckle pattern. If the sphere moves, the interference pattern will change and can be recorded with the camera. In order to retrieve the interesting phase information from the interference pattern the reference beam is slightly tilted with respect to the object wave generating a carrier fringe system on the camera. From this image the phase can be calculated using any of the known algorithms, e.g. the a Carré algorithm [5]. This algorithm shows the advantage to calculate the phase independent from the absolute value of the phase differences between neighbouring pixels on the camera and is relatively stable.

In the non contact situation of the fiber probe, the phase distribution is calculated and recorded as reference.

If the fiber tip is moved in the vertical direction by an amount of  $\Delta z$  the phase of the object wave will change and form a new interference pattern. The phase change  $\Delta\phi$  corresponds

directly to the vertical movement  $\Delta z$  and to the laser wavelength  $\lambda$  according to the following equation:

$$\Delta z = \frac{\Delta\Phi}{2\pi\lambda}$$

As the phase difference can only take values between 0 and  $2\pi$  a linear vertical movement will lead to a periodic saw tooth signal of the phase difference  $\Delta\phi$ . Consequently a demodulation algorithm must be used to determine movements larger than half of the wavelength of the laser. Since this concept can only determine relative movement of the fiber probe, a second laser with slightly different wavelength is used simultaneously, to generate a second phase information. Using both lasers a synthetic wavelength is generated. Within this synthetic wavelength, the position of the fiber probe can be determined in absolute values.

The value of the synthetic wavelength can be calculated as

$$\lambda_{syn} = \frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$$

The synthetic wavelength also indicates the range of the absolute position, which can be detected.

In order to record the phase of both lasers, the interference patterns have to be separated. This is done by tilting the reference beam in the vertical direction with laser 1 and in the horizontal direction with laser 2. The evaluation of the phases with a Carré algorithm is carried out in the vertical respectively horizontal direction with the two wavelength. In this way, the phase information can be recorded, independently and the synthetic phase as well as each single phase can be obtained.

In fig. 5 the phase signal of two different wavelengths  $\lambda_1 = 635$  nm and  $\lambda_2 = 675$  nm is displayed. The synthetic wavelength is  $\lambda_{syn} \sim 10$   $\mu$ m. The synthetic wavelength can be used to determine the absolute position of the sphere. Once this is done, the result of the single wavelength measurement can be used to obtain the high resolution of single wave measurement.

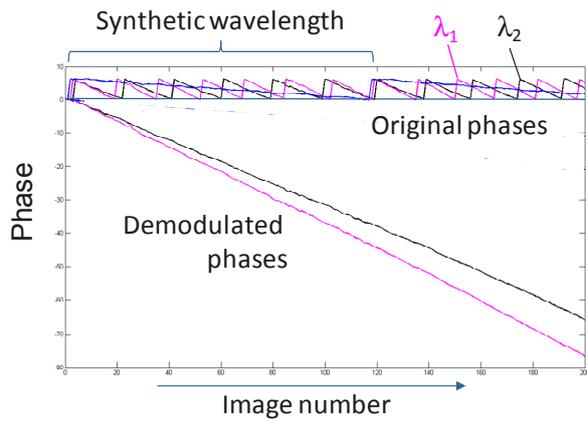


Fig. 5: Measurement result with 2 wavelength

### Test results

A first test setup has been realized in the laboratory to prove this concept, fig. 6. A 3D nano positioning system served to simulate different surface positions.

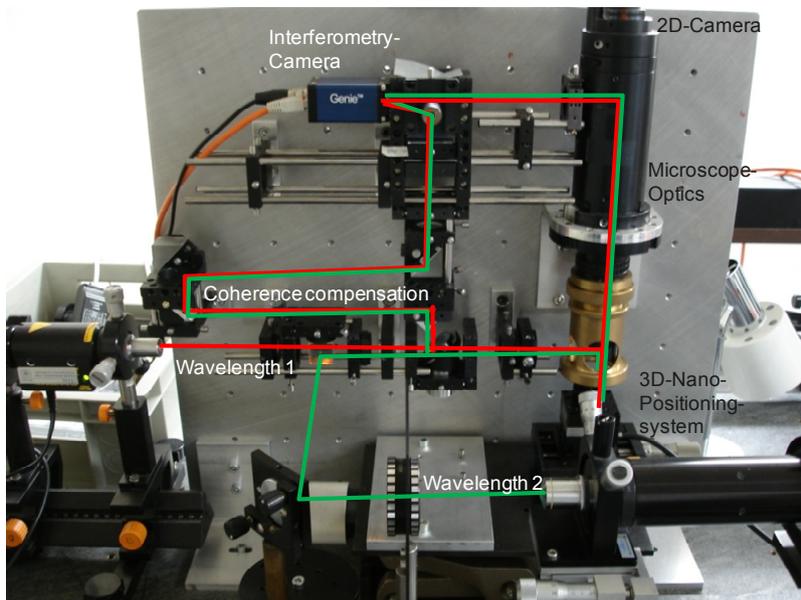


Fig. 6: Test set-up for 2 wavelengths interferometry (in the image HeNe lasers have been used instead of diode lasers as described in the text)

First tests showed, that the phase changes according to movements in lateral direction (x and y) are in the order of 10 times less than changes in the z-direction. Therefore, the lateral and vertical position can be evaluated separately with the 2D camera (lateral) and the interference camera (vertical).

First linearity tests proved the function of this measuring concept. Measurements have been carried out in parallel with the new fiber probe concept and a commercial laser interferometer. The difference between both methods is below 0.1  $\mu\text{m}$ , fig. 7. The systematic increase of the deviation is very likely the result of two different measuring positions of laser interferometer and fiber probe on the nano positioning table (Abbe error).

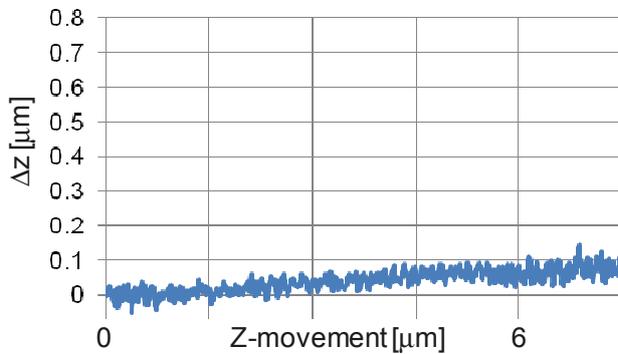


Fig. 7: Difference between laser interferometer and fiber probe measurement

### Further work

The present work has shown that the principle speckle interferometry can successfully be used to determine the z-position of the sphere of a micro fiber probe. The main advantage of this approach is the high measuring sensitivity well below 0.1  $\mu\text{m}$  and the fact, that the movement of the sphere itself is monitored. The present results are promising and show, that measuring resolution in the range of several 10 nm should be achievable. Main focus will be laid in the future to transform the setup into a prototype, which can be applied to a coordinate measuring system.

## **Acknowledgment**

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WERTH - Fiber Probe WFP 3D, product data sheet no. PI388-8-11.

WERTH homepage: [www.werthmesstechnik.de](http://www.werthmesstechnik.de)

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